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Water Quality and Habitat Evaluation of Bass Harbor Marsh Acadia National Park, Maine

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Technical Report NPS/NESORNR/NRTR/95-31

August, 1995

Department of the Interior
National Park Service
New England System Support Office

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EXECUTIVE SUMMARY

The Bass Harbor Marsh estuarine system is located on Mount Desert Island, Maine. Much of the system lies within the boundaries of Acadia National Park. The main creek of Bass Harbor Marsh meanders for 3 km, with mean salinity ranging from 22 ppt at the mouth to freshwater at the upstream tidal end. Tidal range in Bass Harbor is over 3 m, however, range in the marsh-estuary is dramatically dampened to 0.3 m by a natural bedrock sill and road causeway at the marsh mouth. Qualitative observations over the past decade have suggested that macroalgae biomass in the estuary has increased and the recreational fishery (Brook Trout, *Salvelinus fontinalis*) has declined. These reports, coupled with the documented knowledge that a landfill near the headwaters of the system is leaching nitrogen into the Bass Harbor Marsh system, provided incentives for the National Park Service to initiate a study of water and habitat quality of the marsh ecosystem. The specific objectives of the study were to, 1) quantify the major sources of nutrients to the marsh-estuary and evaluate the distribution of nutrients within the system, 2) evaluate the fate of nutrients in the system, especially regarding relationships between macroalgae biomass and nutrient concentrations, 3) predict the distribution of nutrients in the system given various management scenarios (e.g., reduce nitrogen loading from the landfill), and 4) characterize the habitat ecology of the estuary with a focus on submerged aquatic vegetation, fish and macrobenthos.

Seven water quality surveys were conducted (Nov. 1990; May, June, Sept., Oct. 1991; Apr., July 1992). For each survey nutrient loading into the estuary (from freshwater brooks and the ocean) and the distribution of nutrients within the estuary were determined. A steady state box model was developed to evaluate the behavior of nutrients within the system, while a STELLA steady state model was employed to predict nutrient distributions given changes in nutrient loading (e.g., decrease nitrogen loading from Marshall Brook -- the drainage with the landfill). The water quality constituents sampled throughout the study included dissolved inorganic nutrients (ammonia, nitrate+nitrite, phosphate, silicate), total nitrogen, total phosphorus, chlorophyll a, dissolved organic carbon, and dissolved oxygen.

Marshall Brook exhibited the highest concentrations of nitrate+nitrite (range 6-21 umol/l) compared to the other brooks (0-6 umol/l). Marshall Brook was also the dominant freshwater source of nitrate+nitrite to the estuary. When oceanic and freshwater nutrient input to the system were compared, 52% of the total dissolved inorganic nitrogen (ammonia, nitrate+nitrite) entering the estuary was from freshwater sources, while only 5% of the dissolved inorganic phosphorus (phosphate) was from freshwater brooks. These inputs and their subsequent mixing reflect, in part, the distribution of nutrients within the estuary. Macroalgae grow optimally in waters with a ratio of N:P of near 16:1. In Bass

Harbor Marsh the 16:1 ratio occurred in the lower basin, and as expected, this was the zone of high macroalgae biomass (peak = 171 g dry wt/m^2). Our modeling predicts that if dissolved inorganic nitrogen loading from Marshall Brook were decreased to levels equivalent to the other freshwater brooks entering the system, the zone of 16N:1P waters would dramatically shift upstream. Macroalgae growth in the lower basin would probably be reduced.

With regard to habitat quality, adult and juvenile fish were collected throughout the system with a beach seine on eight sample dates from October 1990 through August 1992. Twenty-three species were collected, with common mummichog (*Fundulus heteroclitus*), fourspine stickleback (*Apeltes quadracus*) and Atlantic silverside (*Menidia menidia*) dominating the saline and brackish portions of the system. At the freshwater end, brook trout, golden shiner (*Notemigonus crysoleucas*), and other typical species were collected. The fish fauna of Bass Harbor Marsh appear similar to other shallow estuaries in Maine, and elsewhere in New England. Fish abundance was low in the macroalgal habitats, perhaps a real finding or an artifact of difficult seining conditions.

Benthic macrofauna were sampled with 2 inch diameter cores and a larger 6.5 inch core. Sample dates were as stated above for fish fauna. Salinity and habitat type appeared to be the most important factors affecting the distribution, species composition and abundance of benthic species in Bass Harbor Marsh. Opportunistic species, such as the polychaetes *Capitella capitata*, *Streblospio benedicti*, and *Polydora ligni*, and the bivalve *Gemma gemma* often indicate enriched conditions. The occurrence of these species in moderate abundances at Bass Harbor Marsh may indicate that the system is tending toward a nutrient enriched status or their presence may be in response to the harsh environment created by the highly variable salinity regime in the Bass Harbor Marsh system.

The Bass Harbor Marsh estuary appears to support fairly typical New England marsh-estuarine fish and benthic communities. However, there are some indications suggesting that the Bass Harbor Marsh estuary could tend toward eutrophied or nutrient-enriched conditions. In particular, dense growth of macroalgae is often a response to nutrient enrichment. Given the high nutrient loading from Marshall Brook, coupled with zones of high macroalgal biomass, it seems that implementation of a long-term monitoring program is warranted. Components of a program to monitor nutrient concentrations, nutrient loading, and habitat quality characteristics are provided.

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ACKNOWLEDGEMENTS

Thanks are extended to the Superintendent, Deputy Superintendent, and Resource Management staff of Acadia National Park for providing logistical support and encouragement throughout the study. Special acknowledgements go to David Manski, Robert Breen, Judy Hazen-Connery, and Karen Anderson for their continuous support. At the University of Rhode Island, Graduate School of Oceanography, our research program was greatly facilitated by numerous students and staff, most notably, Laura Reed, Brendhan Zubricki, Melissa Swanson, Charles Farris, Eric Klos, Tara Schraga, Sheldon Pratt, Grace Klein-MacPhee, Edwin Requintina, and Betsy Watkins, among others. Their dedicated efforts in the field and labortory are much appreciated.

This technical report benefited from reviews by the Acadia National Park staff, Mr. Mark Flora (NPS Water Resources Division-Ft. Collins), Dr. Mary Foley (NPS Regional Chief Scientist, Boston), and an anonymous peer reviewer.

Funding for this research was provided by the National Park Service Water Resources Division (Ft. Collins), administered through the National Park Service/National Biological Service Cooperative Park Studies Unit at the University of Rhode Island.

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INTRODUCTION

STATEMENT OF PROBLEM

Bass Harbor Marsh is a marsh-dominated estuary located on the southwest coast of Mount Desert Island, Maine (Fig. 1). The marsh-estuary is the largest tidal marsh system on Mount Desert Island and is mostly within the boundary of Acadia National Park. Over the past decade anecdotal reports (i.e., qualitative observation) have suggested that floating green macroalgal biomass (*Enteromorpha* sp., among others) has substantially increased in the marsh. Increased growth of macroalgae has been reported in other shallow estuarine systems as a symptom of eutrophication and may be related to high nutrient inputs (Waquoit Bay, MA, Valiela et al. 1990; Peel-Harvey estuary, Australia, Sewell 1982, McComb et al. 1983; coastal ponds, RI, Lee and Olsen 1985, Harlin and Thorne-Miller 1981).

The Bass Harbor Marsh watershed is relatively undeveloped; however, some sources of anthropogenic nutrients are of concern. There is a landfill near the headwaters of the system and residential/commercial development along the shoreline of Bass Harbor at the mouth of the marsh-estuary. Marshall Brook, a tributary to the Bass Harbor Marsh estuary (Fig. 2), receives leachate from the Worcester Landfill, most notably in the form of ammonia (Hansen 1980, Gerber Inc. 1989, Soukup and Mitchell 1981). High ammonia concentrations in landfill leachate plumes are typical (Johansen and Carlson 1976). Some residential and commercial development is also found within the Marshall Brook watershed. Along the shoreline of Bass Harbor, in the town of Tremont (including Bernard, Bass Harbor and Tremont), there are over 20 licensed (by ME Dept. of Environmental Protection) "overboard discharge" systems. These are on-site septic systems, and in particular, those with a sand filter have little removal of nitrogen from the wastewater prior to direct discharge into the Harbor.

The National Park Service initiated this study based on several important factors: the perceived eutrophication of the estuary expressed as high macroalgae biomass; anecdotal reports of a declining recreational brook trout (*Salvalinus fontinalis*) fishery; knowledge of potential human-induced sources of nutrients to the system; and a general lack of quantitative data on the ecology and water quality characteristics of this major marsh-estuary in Acadia National Park.

OBJECTIVES OF STUDY

The objectives of this study were severalfold:

1) Quantify, on a seasonal basis, the major sources of nutrients (nitrogen and phosphorus) to the marsh-estuary and evaluate the distribution of nutrients throughout the system.

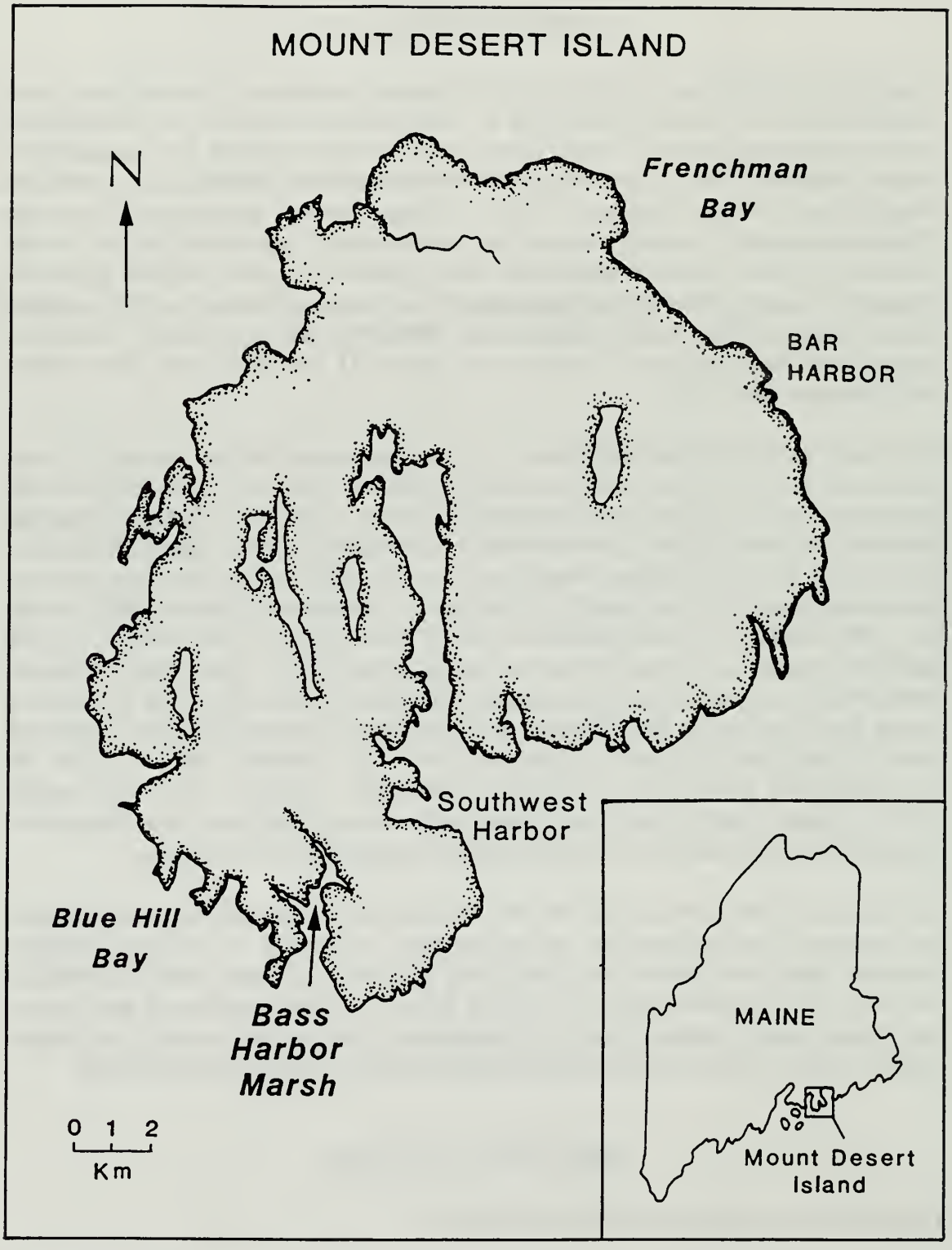


Fig. 1. Location of the Bass Harbor Marsh study site on Mount Desert Island, Maine.

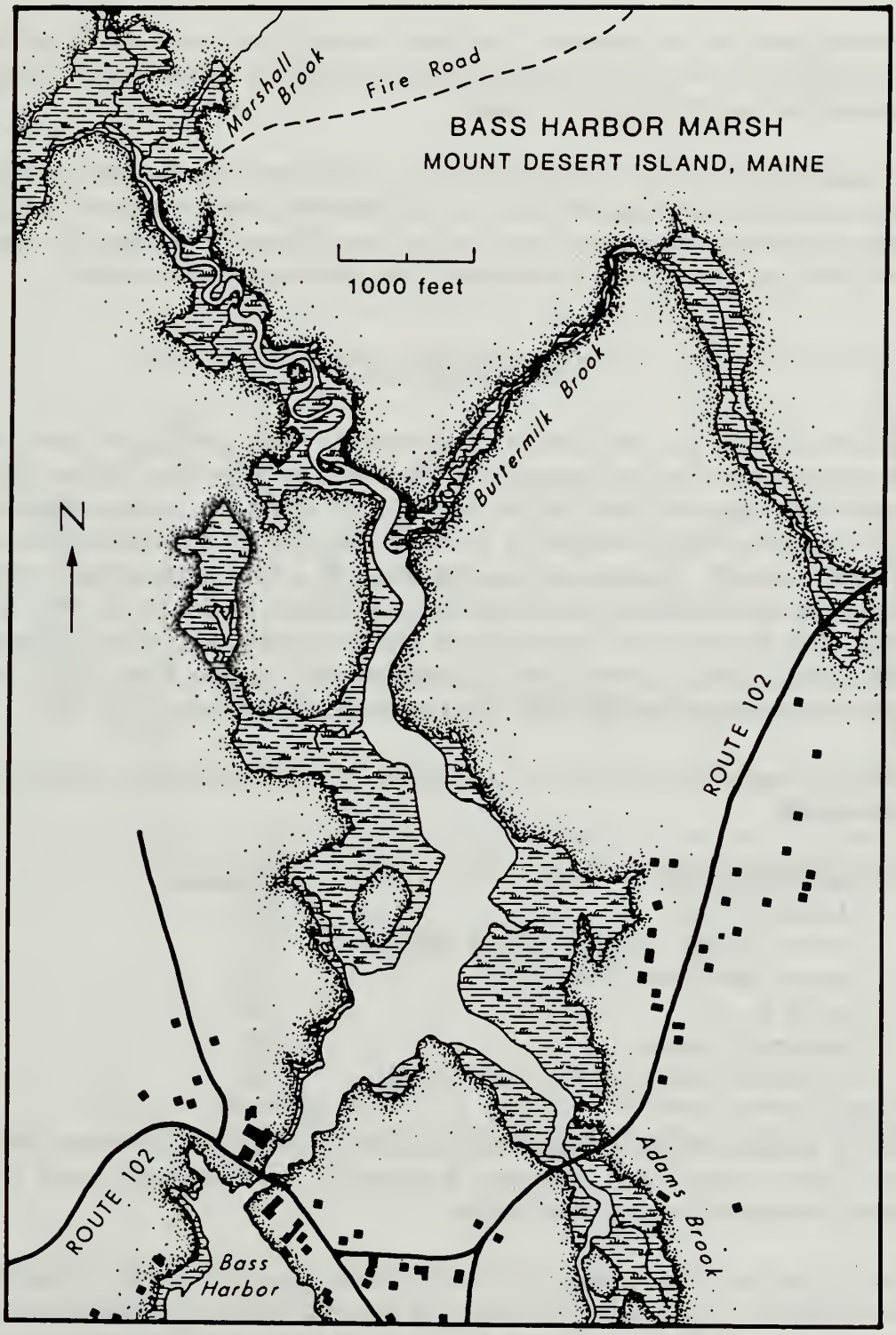


Fig. 2. Bass Harbor Marsh study site. Note freshwater drainages.

2) Evaluate the fate of nutrients within the marsh-estuary, especially with regard to relationships between macroalgae biomass and nutrient concentrations.

3) Develop simple box models of the marsh-estuary to predict the distribution of nutrients in the marsh-estuary given a reduction or increase in nutrient inputs from anthropogenic sources.

4) Characterize the habitat ecology of the marsh-estuary by evaluating the seasonal biomass of macroalgae and submerged aquatic vegetation along the estuarine gradient and by sampling for fish and macrobenthic species composition and relative abundance throughout the marsh-estuary.

THE STUDY SITE

Bass Harbor Marsh is a true estuarine ecosystem with freshwater input from several streams and direct exchange with the ocean, through Bass Harbor (Fig. 2). The mean tidal range in Bass Harbor is over 3 m, while the range in the marsh (< 0.3 m) is substantially reduced by a natural bedrock sill and a road causeway at the marsh mouth. Because of this sill, there is a strong asymmetry in tidal duration with flood tides only entering the marsh basin for 2-3 hours, with a 9-10 hour ebb. The main creek of Bass Harbor Marsh meanders for approximately 3 km, with mean salinity (mean flood and ebb waters) ranging from 22 ppt at the mouth to freshwater at the upstream tidal reaches of the estuary (Fig. 3).

The Bass Harbor Marsh watershed comprises 2,178 ha, associated with several sub-watersheds.

Sub-Watershed	Area (ha)
Marshall Brook	652
Adams Brook	501
Lurvey Brook and China Hill	315
Heath Brook	293
Buttermilk Brook	259
Un-named area (N of Tremont School)	158

In terms of actual wetland area throughout these watersheds, there are 349 ha of marshes, tidal creeks and streams, submerged aquatic beds, and shrub-dominated wetlands, among other types.

Regarding the land use in these sub-watersheds, Marshall Brook contains the most development, including the Worcester Landfill, residential dwellings along Freeman Ridge and Seal Cove Road and limited commercial operations on Seal Cove Road. The Adams Brook watershed contains some limited residential development and an abandoned landfill, but most of this 501 ha watershed lies within the park boundaries and includes Big Heath. The Heath Brook and

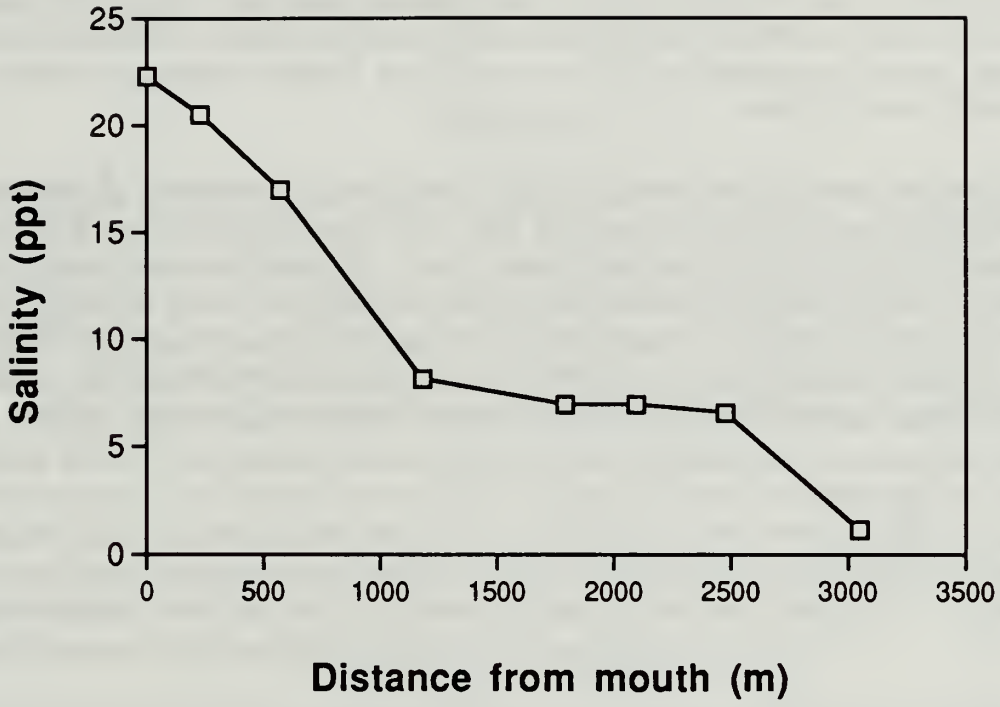


Fig. 3. Average salinity, measured on seven sample surveys, along the estuary from the mouth to the freshwater end.

Lurvey Brook/China Hill drainages are almost exclusively within the park and contain no development activities. The un-named 158 ha watershed at the southern end of the ecosystem includes some residential development and an overboard discharge associated with the Tremont school and town office complex.

The vegetation of Bass Harbor Marsh is described by Calhoun et al. (1994). Typical of New England salt marshes, short form *Spartina alterniflora* (saltwater cordgrass), *S. patens* (salt hay), *Distichlis spicata* (spikegrass), *Juncus gerardii* (blackgrass) and barren salt pannes are found within the lower reaches of the estuary where salinities are relatively high (0-1 km upstream from mouth). A diversity of other marsh plants, such as *Festuca rubra* (red fescue), *Agrostis gigantea* (creeping bent grass), *Potentilla anserina* (silverweed) and others also occur in this lower basin. With a progression toward the more brackish and freshwater tidal marsh habitats the vegetation becomes quite diverse and may include *Spirea tomentosa* (steeplebush), *Spirea latifolia* (meadowsweet), *Myrica gale* (sweet gale), *Carex paleacea* (chaffy sedge), and *Typha angustifolia* (narrow-leaved cattail), among others.

Submerged aquatic vegetation occurs throughout the estuary. *Ruppia maritima* (widgeon grass) occupies much of the brackish water portion of the estuary (about 500-1800 m from the mouth; see Fig. 3). It is particularly dense in Adams Brook. Small, sparse patches of *Zostera marina* (eelgrass) were noted in the lower basin. Toward the freshwater areas, the widgeon grass gives way to *Potamogeton* sp. As previously stated, green macroalgae (mostly *Enteromorpha* sp., with some *Cladophora* sp. and *Rhizoclonium* sp.) occurs throughout the lower basin.

BIOMASS AND DISTRIBUTION OF MACROALGAE AND SUBMERGED AQUATIC VEGETATION

INTRODUCTION

Although anecdotal evidence suggests that macroalgae and submerged aquatic vegetation (SAV) are increasing in the system, there are no quantitative data to support this. In this portion of the study we began a baseline data set on the seasonal biomass trends and distribution of macroalgae and SAV in the estuary. Further, to couple the biomass data with our nutrient loading studies, estimates of the nitrogen content of the plant biomass are included. Finally, dense growth of macroalgae is reported to lead to high rates of oxygen consumption (Valiela et al. 1992), leading to anoxia and habitat degradation. Thus, we report on dissolved oxygen levels throughout the estuary.

METHODS

Three sample sites, representing areas dominated by *Ruppia*, *Potamogeton*, and filamentous green macroalgal beds, were delineated in Spring 1991 (Fig. 4). The macroalgal beds were dominated by *Enteromorpha*, with other green filamentous species also present. No attempt was made to sort the algal samples by species. At 12-21 day intervals from 21 May to 23 October 1991, ten (10) samples from each sample site were harvested with a 0.035m^2 circular quadrat. From a small boat, the quadrat was haphazardly inserted into the sediment and all plant material within the quadrat (aboveground, belowground, and floating material) was collected on a 2 mm mesh sieve. Given the soft, muddy texture of the sediment, both above and belowground SAV plant parts were easily harvested. In the field the samples were washed free of sediment and dead plant material, visible animals and non-target plant material were removed (i.e., occasional *Ruppia* plants were associated with the macroalgal sample area).

In the laboratory, each sample was rinsed with deionized water and dried to a constant weight at 60°C. Dry weight of each sample was determined using a digital top-loading balance (Sartorius, Type L-610-D). Biomass was calculated as g dry plant tissue m^{-2}. Each dry sample was then ground to a fine powder for carbon and nitrogen analysis using a mortar and pestle and stored frozen. The frozen, powdered plant samples (stored from 3-7 months) were thawed and dried at 60°C to remove any newly condensed water. From 200 to 800 ug of each sample were weighed into a small, tin capsule and combusted on a Carlo-Erba NA 5000 CHN analyzer equipped with an integrator. Carbon and nitrogen peak areas were compared to an acetanilide standard curve to yield absolute concentrations in mg g^{-1} dry plant tissue.

BIOMASS

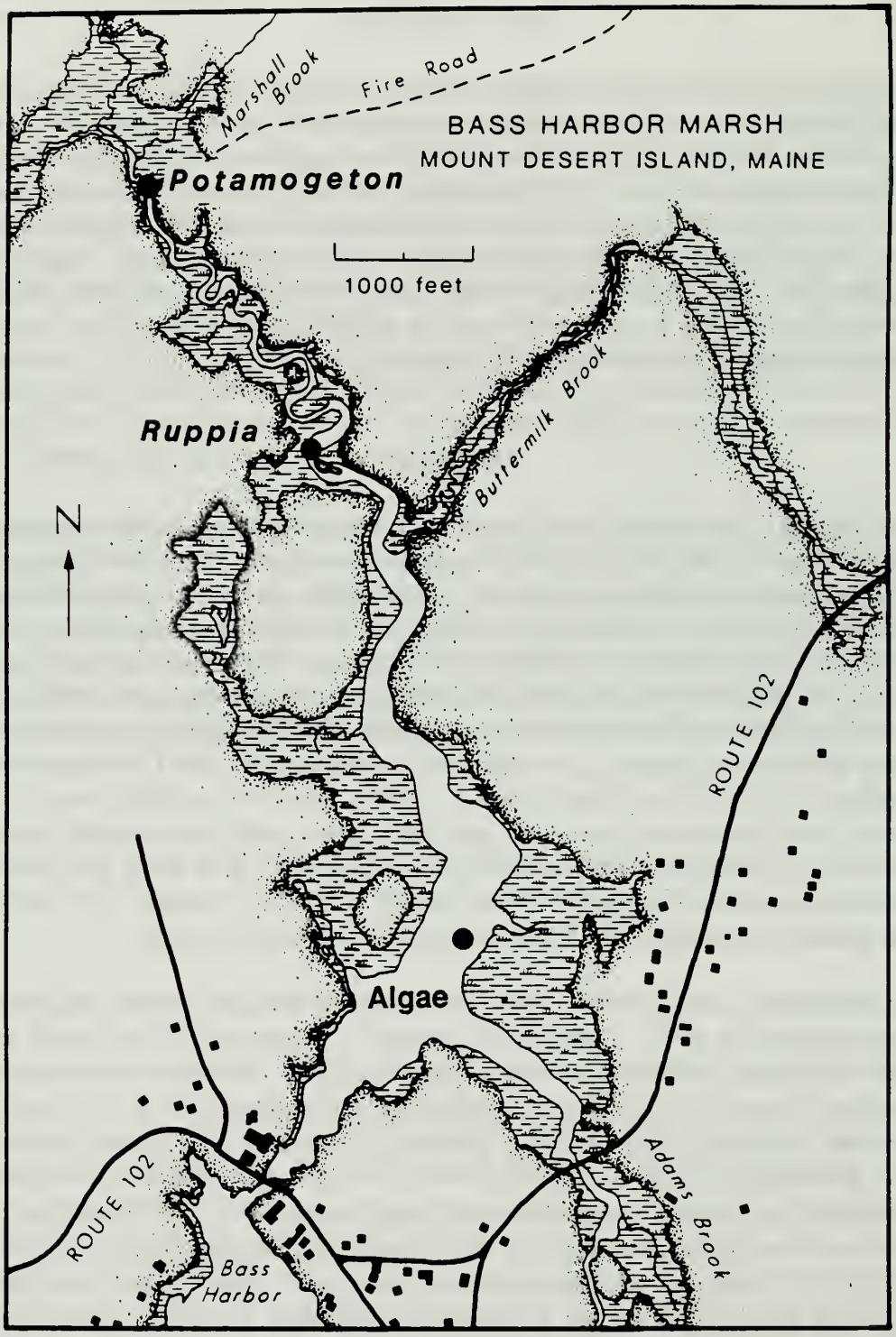


Fig. 4. Location of sampling stations for macroalgal, Ruppia, and Potamogeton biomass sampling.

Dissolved oxygen concentrations were determined within the dense macroalgae bed (station 3, see Fig. 7) at approximately hourly intervals for diurnal periods on 16 June 1992 and on 21 July 1992. Measurements were taken at 25 cm below the surface and 25 cm above the bottom with a Hydrolab Surveyor II. During a 12 May 1992 sampling trip dissolved oxygen was determined at all 9 water quality sampling stations (see Fig. 7) within 1 hour of low, high, and then low slack water. On 17 and 20 August 1992, dissolved oxygen was measured at the various sample stations encompassing the dawn to dusk period.

RESULTS AND DISCUSSION

Plant Biomass

Three major species of submerged aquatic vegetation occur in Bass Harbor Marsh--the freshwater angiosperm, *Potamogeton*, the brackish water angiosperm, *Ruppia maritima* and floating or attached marine macroalgae (*Enteromorpha* and others). It is important to note that spatially the distributions of macroalgae and *Ruppia* overlap, while *Potamogeton* is discrete from the other two in the marsh. All three species showed a peak in biomass during the 1991 sampling period. macroalgae peaked in mid-June while *Ruppia* and *Potamogeton* peaked in late July (Fig. 5). All three exhibited a decline in August. While macroalgae and *Potamogeton* recovered by September-October, the biomass of *Ruppia* remained low. The biomass curves for *Ruppia* and macroalgae suggest temporal partitioning over the growing season. *Ruppia* shows one major accumulation of biomass in July. The biomass of macroalgae peaks both before and after *Ruppia* but remains relatively low when *Ruppia* is high. Thus, in the lower marsh basin where these two communities co-occur, both space and utilization of nutrients appear to shift seasonally from macroalgae to *Ruppia* to macroalgae. When compared to macroalgal peak biomass estimates from other shallow estuarine systems in New England, and elsewhere worldwide, the biomass at Bass Harbor Marsh does not appear excessive (Table 1).

Estimates of the total nitrogen content in the plant tissue are provided (Table 2 and Zubricki, 1992). These data will be revisited when interpreting the relationship between algal and SAV biomass and water column nutrient concentrations (next section of report).

Oxygen Concentrations

Dissolved oxygen concentrations within the dense macroalgal mats do not approach anoxia, although there is a trend toward oxygen removal by respiration during pre-dawn and dawn, as would be expected (Fig. 6 a,b). These data were collected in mid-June and late July when macroalgae biomass was near its peak, water temperatures were beginning to warm and dawn samples were at ebb tide

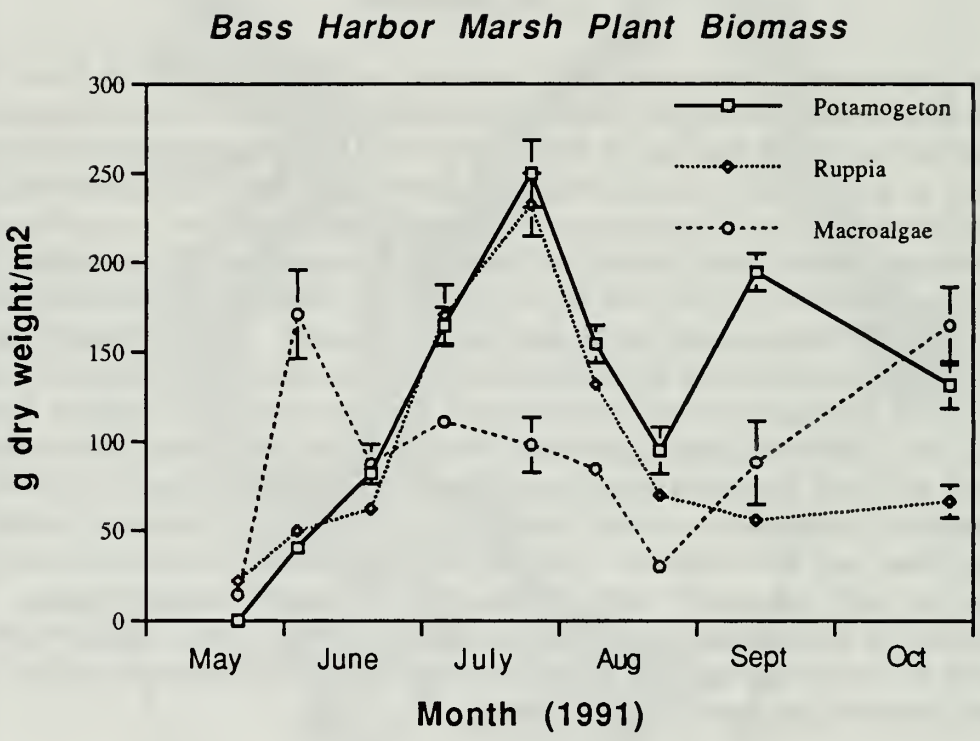


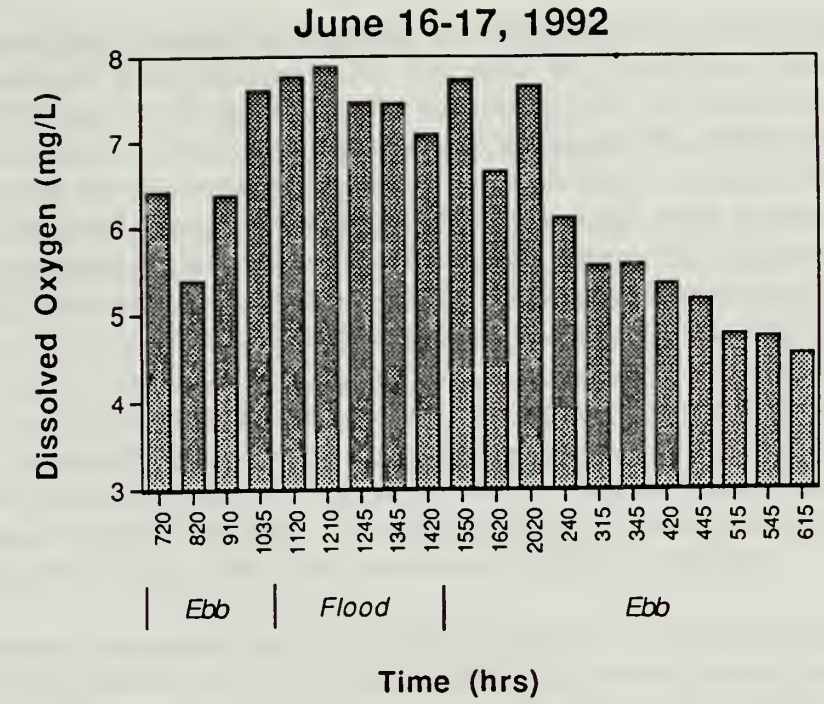
Fig. 5. Biomass of submerged vegetation and macroalgae during the 1991 growing season. Mean ± SE.

Table 1. Biomass of green filamentous macroalgae in Bass Harbor Marsh compared to other estuarine systems.

Study Site (Reference)	Mean Annual Biomass g dry/m^2	Peak Biomass g dry /m^2
Waquoit Bay, MA		
- Childs River	220 ± 29	
- Quashnet River	85 ± 11	
- Sage Lot Pond	36 ± 6	
(Valiela et al. 1992)		
Nauset Marsh, MA		
- Dense site		638
- Sparse site		60
(Roman et al., 1990)		
Peel-Harvey Estuary, Australia (McComb et al. 1983)		1,200
Trosa-Askö, Baltic, Sweden (Wallentinus 1976)	144	450
Bass Harbor Marsh, ME (This Study)	92 ± 50	171

Table 2. Nitrogen content of submerged vegetation community types in Bass Harbor Marsh. All data are from 1991.

Date	Cover Type	Area Covered (m^2)	Biomass (g dry plant/m^2)	% N	g N/m^2
May 21	Algae	33982	14.0	1.7	0.2
	Ruppia	32364	24.8	3.0	0.7
	Potamogeton	0	0.0	0.0	0.0
June 3	Algae	157772	171.2	1.6	2.7
	Ruppia	146445	49.8	2.8	1.4
	Potamogeton	16505	40.4	4.3	1.7
June 19	Algae	78482	87.4	1.7	1.5
	Ruppia	92236	63.0	2.8	1.8
	Potamogeton	10195	82.3	3.8	3.2
July 5	Algae	135118	111.0	3.3	3.7
	Ruppia	86572	170.8	2.7	4.7
	Potamogeton	9466	165.1	4.0	6.6
July 24	Algae	72818	98.1	3.8	3.8
	Ruppia	122981	232.7	3.1	7.1
	Potamogeton	6068	250.0	3.4	8.4
Aug. 7	Algae	69582	84.4	4.6	3.9
	Ruppia	131881	132.2	3.1	4.1
	Potamogeton	7282	154.8	3.6	5.6
Aug. 21	Algae	33173	29.8	5.2	1.5
	Ruppia	138354	69.9	3.1	2.2
	Potamogeton	8010	95.1	4.1	3.9
Sept. 11	Algae	18609	88.1	3.4	3.0
	Ruppia	137545	56.0	3.0	1.7
	Potamogeton	7525	195.0	3.0	5.9
Oct. 23	Algae	15373	147.1	3.2	4.7
	Ruppia	153727	68.0	2.6	1.7
	Potamogeton	8495	148.0	2.4	3.6



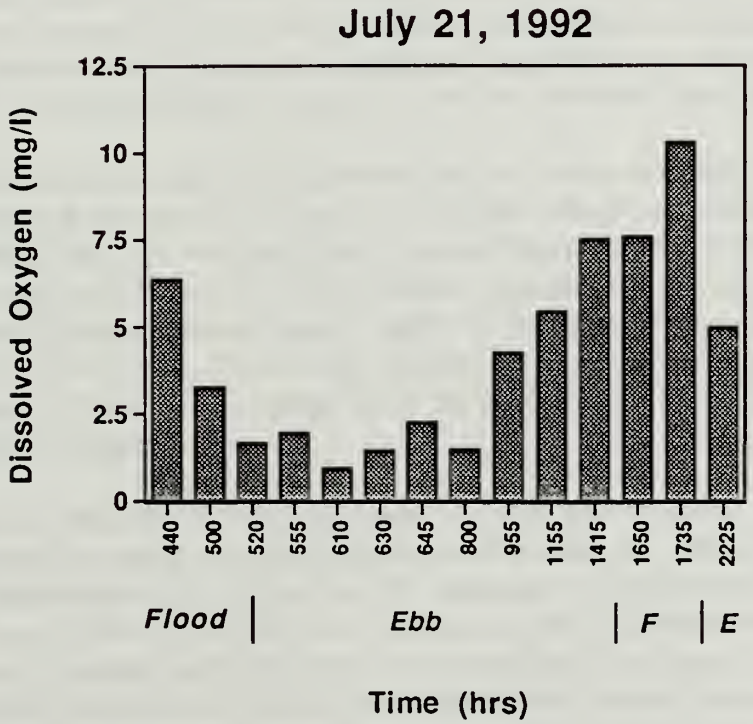


Fig. 6. Dissolved oxygen, measured 10cm above the bottom, over diurnal periods at Station 3 in (a) June 1992 and (b) July 1992. Tidal stage is indicated.

-- all conditions that are conducive to hypoxic or anoxic events in shallow estuarine basins. Although the data are not presented here, daytime oxygen measurements were taken throughout the estuary (from the mouth to freshwater end) during May 1992 and August 1992 and concentrations never dropped below 8 mg/l. Based on our limited data set it cannot be conclusively stated that the macroalgal beds of Bass Harbor Marsh experience chronic hypoxic or anoxic events. However, if such events do occur it is likely that they are not prolonged. Studies elsewhere have reported anoxic or hypoxic events in association with dense macroalgal beds (Nixon et al. 1976, Valiela et al. 1992).

WATER QUALITY AND HYDRODYNAMIC MODELING

GOALS AND APPROACH

The goal of the water quality sampling program was to quantify and define the relative importance of nutrient inputs to the marsh, the concentrations in the marsh basin, and ultimately the fate of nutrients within the system. Nutrient inputs to the marsh include both external (freshwater brooks and ocean) and internal (flux from the sediments) sources. External atmospheric nutrient inputs are not considered in this assessment of the data. Internal sources of dissolved inorganic nutrients such as flux from the sediments often involve recycling of nutrients previously bound in organic matter. External sources such as brooks and streams deliver nutrients mostly in inorganic form, immediately available for utilization by algae and other submerged aquatic vegetation.

Atmospheric deposition as a source of nutrients to the marsh-estuarine system was not addressed in this study. Recent studies have suggested that atmospheric nitrogen deposition may be an important fraction of the total anthropogenic nitrogen loading to coastal systems; however, there is extraordinary uncertainty in estimating the quantity of nitrogen deposited on the watershed from the atmosphere that ultimately reaches coastal or estuarine waters (Hinga et al. 1991). In our study, it is assumed that by sampling the major stream inputs and ocean input that we adequately captured a significant portion of atmospherically deposited nutrients from throughout the Bass Harbor Marsh watershed.

We did not address internal nutrient sources in our sampling scheme. Rather we concentrated on external inputs as these comprise the ultimate source of nutrients to the system, and feed internal sources which depend on recycling. Studies are underway in Bass Harbor Marsh to address nutrient exchange processes at the sediment-water interface. Expected completion of these studies is in the fall of 1995 (Charles N. Farris, Ph.D. dissertation research, Univ. RI, Graduate School of Oceanography and National Park Service Cooperative Education Program).

Measuring the input of nutrients via stream or river discharge requires knowledge of nutrient concentration and volume of water discharged per unit time. Estimates of the latter can be obtained using gauges, weirs, or as in our case, cross-sectional profiles of area and velocity. Input from the ocean requires the same information but is usually more difficult to obtain. In general estuaries have wide mouths and the tidal flow across this mouth is non-uniform. Directly measuring the flow of water requires considerable equipment, expense and effort. Even when the tidal flow is constricted, turbulence often frustrates direct measurements.

As an alternative we have chosen a two-phased modeling approach. In the first phase we use a tidal salt balance approach to estimate the flux of water between the marsh and the ocean. These water fluxes and nutrient concentrations are combined to estimate the transport of nutrients from the ocean into the marsh.

In the second phase we use a steady state, tidally averaged box model to estimate the mass of nutrients that should be in the estuary if they behaved conservatively. Conservative mixing is defined as no utilization or production of nutrients within the marsh itself. Comparison of these theoretical estimates with the observed mass of nutrients can reveal whether the marsh itself is a source or sink for nutrients. Thus, using the model, we can begin to examine the fate of nutrients within the system. Further, we employed a STELLA steady state model (Richmond et al. 1987) that allows an examination of nutrient distributions in the estuary given changes in the input from either the freshwater brooks or the ocean.

It is important to note that this study was not designed to identify specific sources of nutrients to the system. Nutrients were measured for all streams entering the marsh and the ocean. Water samples collected were a reflection of all specific sources from a particular watershed (i.e., landfill inputs, residential inputs, atmospheric inputs, etc.).

METHODS

Sampling the Marsh

Seven surveys of the Bass Harbor Marsh estuary were conducted (Nov., 1990; May, June, Sept., Oct., 1991; April, July, 1992). Although spanning 20 months, the surveys provide a composite picture of water quality during the annual growing season (April-November) of submerged aquatic vegetation and macroalgae in the marsh.

On each survey eleven (11) stations (Fig. 7) were occupied within 1 hour of slack high and slack low tide. At each station vertical profiles from surface to bottom of salinity and temperature were obtained with a Beckman Inductive Salinometer or Hydrolab Surveyor II at 0.25 m depth intervals. Depending on the density structure of the water column (well-mixed or stratified), one or two (surface and bottom) water samples were obtained by a hand operated pump for nutrient analysis. Sampling was accomplished from a canoe. In general, three successive slack tides were sampled for salinity and temperature, while two consecutive slack tides were sampled for nutrients, dissolved organic carbon (DOC) and chlorophyll a. The data generated from this sampling scheme provide synoptic pictures of the marsh at 2 (nutrients) or 3 (salinity) points in time over a tidal cycle.

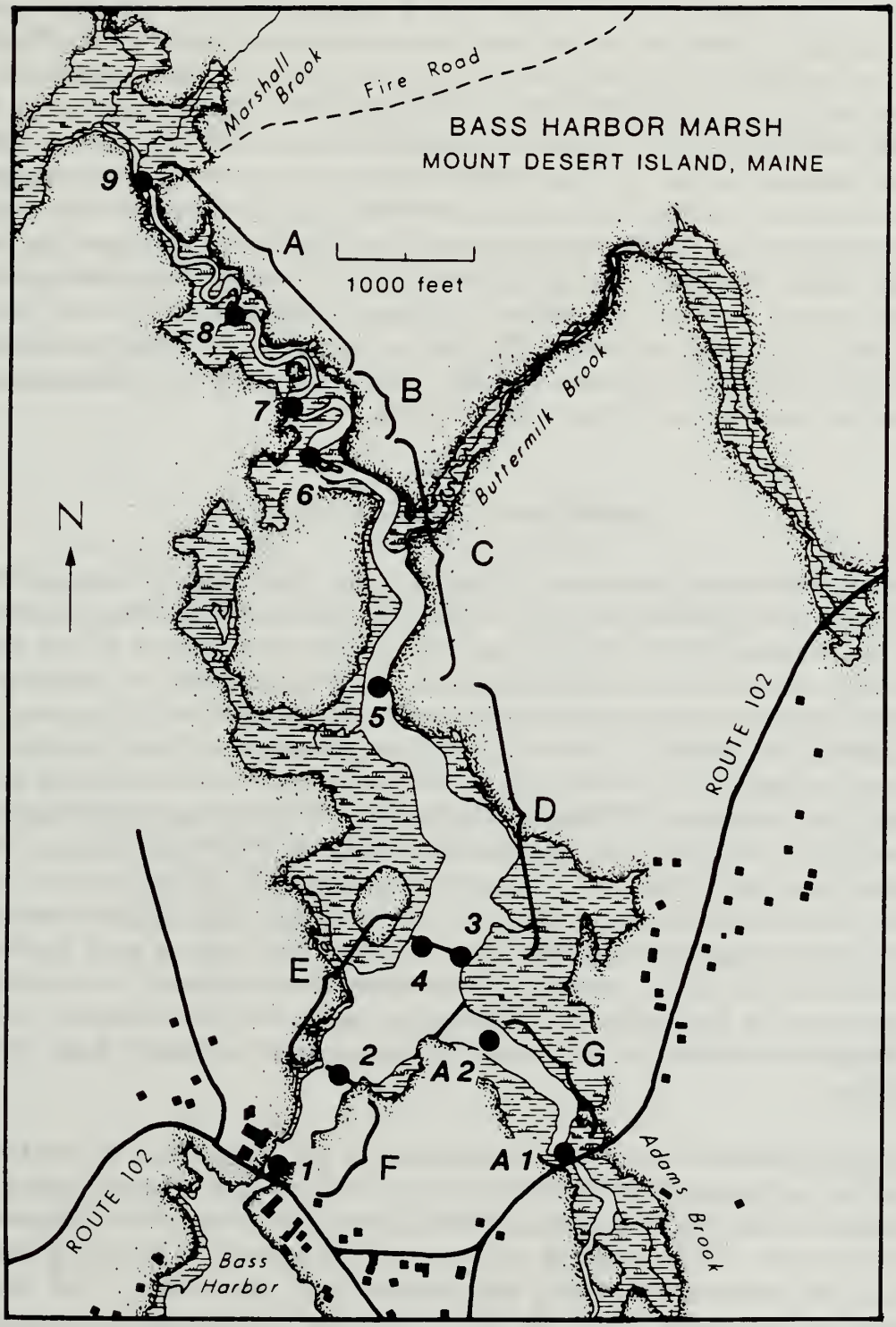


Fig. 7. Location of 11 sampling stations from the harbor to the freshwater end of the estuary. Segments used in modeling the system are indicated by letters.

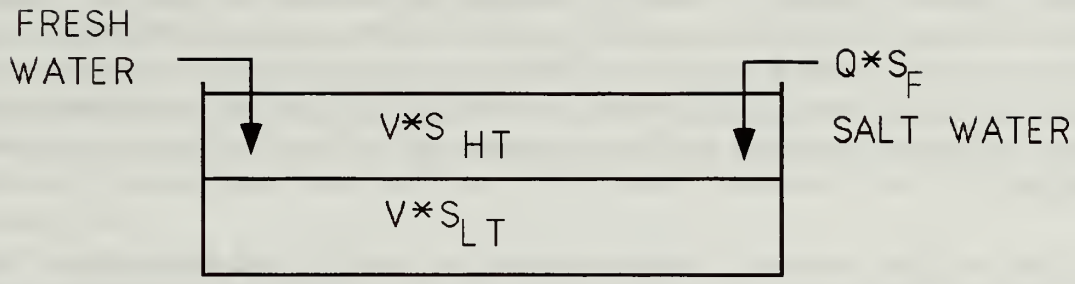
The volume of water held in the marsh at each slack tide was determined as the product of surface area and depth. Surface area was determined by digitizing aerial photographs (Black and White, 23 April 1985; scale 1:9000) of the Bass Harbor Marsh basin (i.e., creeks and water basins, not the vegetated marsh surface). The system was divided into 7 segments with 1 station at each boundary (Fig. 7) and the surface area of each segment determined. Depth of water in the system was determined from cross-sectional bathymetric profiles taken at each station. At the time of profiling a tide staff graduated at 5 cm intervals was placed in the substrate and a benchmark tidal height recorded. It was not necessary to survey these staffs relative to a mean sea level datum. A benchmark average depth for each segment was calculated by first determining an average depth for each cross-section and then averaging estimates for cross-sections within a segment, including boundaries. Average depth multiplied by segment surface area yielded segment volume. Since tide staffs were "tied" to benchmark volumes, a segmental volume at any stage of the tidal cycle could be determined. Segmental volumes within 1 hour of slack tide were determined by reading tide staffs as each station was sampled.

Freshwater and Oceanic Inputs

On the day before each survey of the estuary, the discharge of freshwater from five sources was determined (Fig. 2; Adams Brook, Marshall Brook, Buttermilk Brook, un-named brook from China Hill -- hereafter named China Brook, confluence of Lurvey and Heath Brooks). Water samples for nutrients and dissolved organic carbon were also obtained. At an established location along each freshwater stream, a transect line, graduated in 0.25 m intervals was deployed perpendicular to water flow, and water depth was measured at each interval. By integration, cross-sectional areas were generated. The sum of the sectional areas was the total cross-sectional area of a particular stream. Each sectional area multiplied by a velocity measurement taken with a Marsh-McBirney electromagnetic current meter at 60% of the depth in the center of the section yielded a sectional volume flow. Volume discharge of each freshwater source was calculated by summing the sectional flow volumes. Nutrient input was calculated as the product of volume discharge and concentration. During 1991 freshwater discharge was measured fortnightly from early May through September.

The flood tide flux of ocean water into the marsh was determined by salt balance and on two occasions (November 1990; May 1991) by direct measurement. The salt balance model (Fig. 8, equation 1) simply says that at any time t, the mass of salt in the marsh, VS (where V is volume and S is salinity) is changing at a rate equal to the mass of salt being transported from the ocean. This mass is expressed as the product of Q, the flood tide water flux per unit time, and the concentration of salt, S_F, in ocean water. Equation 2 (Fig. 8) expresses the salt balance over a half tidal cycle. Thus if the mass of salt in the estuary at low tide

TIDAL BOX MODEL



$$1) \quad Q^{*}S_{F} = \frac{d\ V^{*}S}{d\ t}$$

$$2) \quad Q_{F} = \frac{V^{*}S_{HT} - V^{*}S_{LT}}{S_{F}}$$

Fig. 8. Tidal box model of Bass Harbor Marsh.
V = volume
S = salinity
HT = high tide
LT = low tide
F = flood tide
Q = oceanic water transport

and the ensuing high tide, as well as the average salinity of ocean water are known, Q_F the flood tide water flux can be calculated.

The mass of salt in the estuary was determined from the synoptic surveys. An average salinity for each of the 7 segments at high or low tide was calculated by first averaging measurements over depth at each station and then averaging across stations within a segment. Combined with volume information from tide staffs, the mass of salt in each segment at high and low tide was determined. Summing over segments yielded estimates of the mass of salt in the entire system.

At the bridge (station 1) measurements of salinity and temperature were obtained with a Beckman Inductive Salinometer every half hour on the flood tide and every hour on the ebb tide. Samples for nutrients were taken every half hour over the flood tide. Samples for chlorophyll a and DOC were taken at slack tides only. The salinity of ocean water entering the marsh was calculated as a time-weighted average over the flood tide. Nutrient inputs on the flood tide were calculated as the product of the flood tide water flux (Q_F) and the time-weighted average nutrient concentration on the flood tide.

Direct measurement of the flood tide water flux was conducted at the bridge (station 1) on two occasions (Nov. 1990; May 1991). Coincident measurements of cross-sectional area and current speed were obtained over time in a manner similar to that described for freshwater inputs. Estimates (2/hour) of water flux (volume/unit time) were integrated over the flood tide to yield a total water flux (Q_F).

No estimate of Q_F is without error. Since the concentrations of material in ocean water are usually low but measured accurately, error in the calculated transport of material into the marsh will depend predominantly on error in Q_F. To provide a sense of the error in Q_F we can compare different estimates and assess their level of agreement. We have measured Q_F directly, and estimated it by salt balance. We can also calculate Q_F based on volume change as:

$$Q_F = \frac{dV}{dt} - FWI$$

where $\frac{dV}{dt}$ is the volume change in the estuary over the flood tide and FWI is the freshwater input which accumulates in the system during the flood tide.

Analysis of Water Samples

Water samples were obtained by filling a 1 liter amber plastic bottle. In the estuary these were filled with a hand operated pump. Samples from freshwater brooks were obtained by immersing the bottle 0.25 m below the water surface.

At the bridge (Station 1) bottles were filled from a bucket sample. Aliquots were withdrawn from the amber bottle and processed appropriately for a given chemical analysis.

Within 1 hour of collection, samples for dissolved inorganic nutrients were passed manually, using a syringe, through 47 mm diameter, 0.4 µmoles/l pore size Nuclepore membrane filters into 60 ml plastic bottles. Samples were preserved with 1 drop of chloroform and frozen for later analysis. Dissolved inorganic nutrient concentrations (ammonia, nitrate, nitrite, phosphate, silicate) were determined colorimetrically on a Technicon II autoanalyzer (Lambert and Oviatt 1986).

The concentrations of total nitrogen and phosphorus were determined by first oxidizing organic nitrogen and phosphorus to nitrate and phosphate with the persulfate ion after Valderamma (1981). With all nitrogen and phosphorus converted to inorganic form, the total concentration was measured colorimetrically on a Technicon II autoanalyzer.

The concentration of chlorophyll a was determined fluorometrically using the method of Yentsch and Menzel (1963) as modified by Lorenzen (1966). Duplicate 10 ml aliquots were vacuum filtered (<125 mm mercury) through Whatmann GF/F glass fiber filters and preserved with a magnesium carbonate solution. Filters were wrapped in foil and stored over desiccant in a refrigerator until analysis.

Samples (80 ml) for dissolved organic carbon (DOC) were passed through pre-ashed (450°C) Whatmann GF/F filters (25 mm diameter) into pre-ashed glass amber bottles and preserved with 0.5 ml concentrated phosphoric acid. The concentration of DOC was determined by persulphate digestion on an O.I. Corporation Model 700 TOC Analyzer after Doering et al. (1994).

Steady State Model

Having characterized nutrient inputs from freshwater brooks and from the adjacent ocean, it remains to quantify the contribution of these inputs to the observed distribution of nutrients in the estuary. An estimate of this contribution can be obtained using the steady state box model depicted in Fig. 9.

This one dimensional steady state model has 5 segments and represents non-tidal exchanges in a well-mixed estuary. Both salt and volume are conserved. Two sorts of exchanges are represented: advective (Q) and non-advective (E). In this model Q's are the down estuary transport of freshwater that must occur if volume is conserved and constant. E or non-advective transport may be visualized as equal volumes of water being exchanged between segments. Volume is thus conserved, but since the concentration of material in these equal

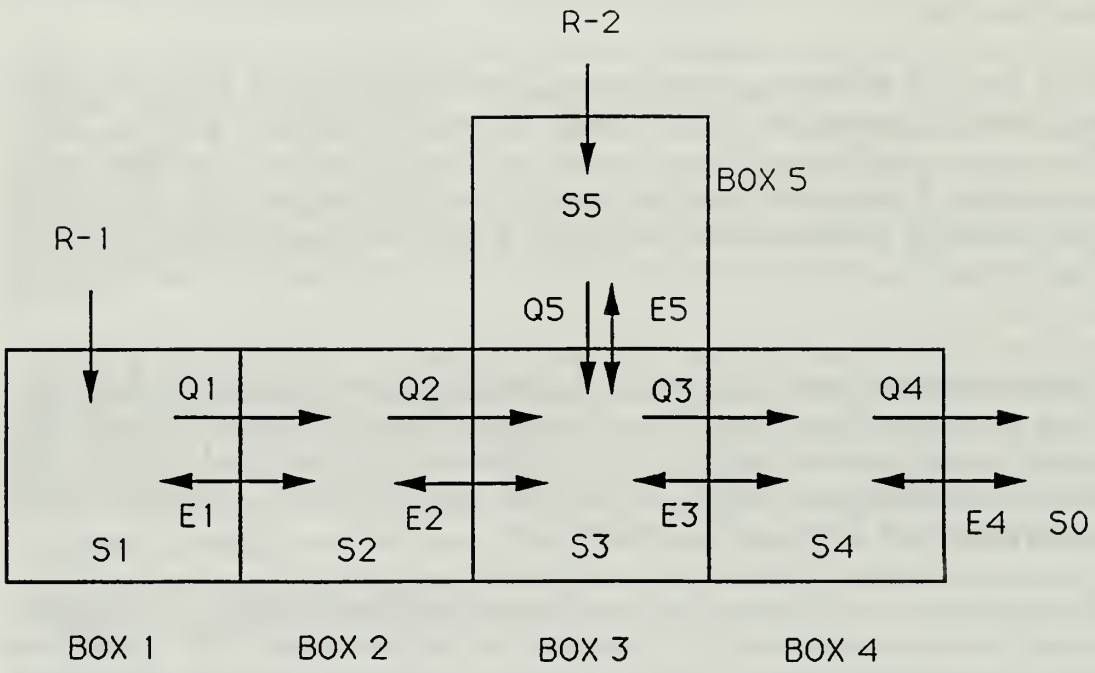


Fig. 9. Steady state box model of the Bass Harbor Marsh estuary.
Box 1 = segments A,B, and C in Fig. 7
Box 2 = segment D
Box 3 = segment E
Box 4 = segment F
Box 5 = segment G
R-1 = combined input from Lurvey+Heath, China, Marshall and Buttermilk Brooks
R-2 = input from Adams Brook
Q = down estuary advective transport
E = non-advective exchange
S = salinity
S0 = ocean salinity

volumes may differ, E can result in the net exchange of material between segments.

If freshwater input, average salinity of ocean water and average salinity in each segment are known then Q's and E's can be calculated algebraically after Officer (1980). Since the model represents non-tidal exchange, tidally averaged salinities were used in the model. These were obtained by calculating an average salinity (S_{ij}) for each of the three slack tides (i = 1-3) in each segment (j = 1-5) sampled. The tidally averaged salinity for a given segment (S_j) is given by:

$$S_j = \left[(S_{1j} + S_{2j}) + (S_{2j} + S_{3j})\right] / 4$$

In general the time-weighted average salinity at the bridge was taken to represent the average salinity of ocean water. In most cases the averaging procedures for segments and ocean water produced the monatonic increase in salinity from the head to the mouth of the estuary represented in the model. On two occasions (June, Sept. 1991) the calculated ocean salinity was less than that in the adjacent segment of the estuary implying the unlikely condition of diffusion against a concentration gradient. This situation may arise from less than synoptic sampling of the estuary or too infrequent sampling at the bridge resulting in an overestimate of average salinity in the segment or an underestimate of average salinity of the ocean. Since there was no way to correct for the former kind of error, average salinity of ocean water at the bridge was recalculated as in equation 1 (see Fig. 8) for these two dates.

Once the transports have been calculated, tidally averaged nutrient concentrations for each segment can be predicted and compared with those measured and observed. An observed tidally averaged nutrient concentration for each segment was calculated as described for salinity except the segmental average was calculated from consecutive high and low slack tides as the third slack tide was not sampled for nutrients. Nutrient concentrations in ocean water at the bridge were similarly calculated. The concentration predicted for each segment is based on the steady state nature of the model: the mass of nutrient entering a segment must also leave it. Thus, the flux of nutrients into a given segment from adjacent segments must equal the flux out of a given segment.

For example, the predicted concentration of a nutrient in segment 2 of the model (Fig. 9) is given by:

1) $$CP_2 * (Q_2 + E_2 + E_1) = C_1 (Q_1 + E_1) + C_3 * E_2$$

2) $$CP_2 = \left[C_1 (Q_1 + E_1) + C_3 * E_2\right] / (Q_2 + E_2 + E_1)$$

Where CP_2 is the predicted concentration in segment 2, C_1 and C_3 are tidally averaged measured concentrations in segment 1 and 3 respectively and Q's and

E's are as previously defined. The left hand side of equation 1 defines the mass of nutrient leaving the segment while the right hand side expresses the mass entering the segment.

Since the transports are known and the concentrations in the adjacent upstream and downstream segments are known, CP_2 can be calculated. This estimated nutrient concentration is that predicted from inputs external to the segment in question. Internal processes such as remineralization or primary productivity are not considered and if important would cause the actual concentration to diverge significantly from the predicted. On the other hand, if observed and predicted nutrient concentrations agree, then concentrations are primarily determined by external inputs, with internal processes having little impact on observed concentrations.

A predicted nutrient concentration was calculated for each segment of the model on each sampling date (total of 35 predictions). In Sept. 1991 there was no freshwater input to segment 5 from Adams Brook and no estimate of nutrient concentration could be made, thus 34 concentrations were predicted. The agreement between predicted and observed concentrations was judged by functional regression of predicted (y), on observed (x) concentration (Ricker 1973). If the slope of this regression is equal to 1.0 then nutrient concentrations are determined primarily by external inputs. A slope less than 1.0 implies that observed concentrations are greater than predicted and nutrients are being added to the estuary. A slope greater than 1.0 implies that observed concentrations are less than predicted and there is loss from the estuary.

The R^2 of the functional regression also furnishes pertinent information. The R^2 indicates the amount of variability in observed concentrations which can be explained by predicted concentrations. Since predicted concentrations in each segment are computed as a function of mixing and input from adjacent segments, by inference the R^2 measures the variability in observed concentrations which may be due to these processes (Doering et al. 1990).

The steady state box model also allows calculation of residence time. Here we calculate the residence time of salt in each segment of the model as:

$$RT_i = (V_i * S_i) / [(E_{i-1} * S_{i-1}) + (Q_{i-1} * S_{i-1}) + (E_i * S_{i+1})]$$

where i = segment of interest, i-1 = upstream segment, i + 1 = downstream segment, s = volume weighted salinity, v = volume (m^3), E and Q are non-advective and advective transports (m^3/sec).

This equation yields the number of seconds it takes for the steady state mass of salt in a segment to be replaced by input from up and downstream segments.

Residence time of salt in the entire system is calculated by summing residence times for each segment.

Steady State STELLA Model

STELLA (Hyperformance Systems, Lyme, New Hampshire) is a time dependent modeling program. In essence it solves differential equations such as

$$N_t = N_o + \frac{dN}{dt}$$

where N_t might be the nutrient concentration at time t, N_o the initial concentration and $\frac{dN}{dt}$ the rate of change in nutrient concentration per unit time. In our application $\frac{dN}{dt}$ for a particular segment in the box model would be given as:

$$\frac{dN}{dt} = \text{(transport in - transport out).}$$

In solving for N_t STELLA uses finite difference equations as discrete approximations to differential equations. For our example the differential equation would be expressed as

$$N_t = N_{t-\Delta t} + \Delta t * \text{(transport in - transport out)}$$

This equation states that the nutrient concentration at any time "t" is equal to the nutrient concentration one time step ago "t-Δt", plus the change in nutrient concentration that occurred over that time step.

STELLA allows us to specify the water transports (Q's) and non-advective exchanges (E's) between each segment of our box model (see Table 12). From these, STELLA can calculate (transport in - transport out). Initial nutrient concentrations in each segment are set to zero and concentrations calculated over time as a function of freshwater and oceanic endmember inputs. Because transports, exchanges and endmember inputs are constant for each survey date the model will come to steady state. Unlike the algebraic solution to the steady state box model presented earlier nutrient concentrations in adjacent upstream and downstream segments need not be specified in order to estimate a nutrient concentration within a given segment. We need only to specify endmember nutrient inputs. Thus, the STELLA software represents an accurate and straight forward tool for examining effects of variation in endmember inputs on the distribution of nutrients in the estuary.

RESULTS

Freshwater Inputs

Total freshwater discharge from all 5 brooks flowing into the Bass Harbor Marsh estuary ranged from a high of 1.27 m^3/sec in June 1991 to a low of 0.0 m^3/sec in July 1991 (Fig. 10). Seasonally, the three years of measurements encompass the period from April to November. Although lowest discharges occurred during the summer, high discharge can occur at any time in response to rainfall. Our measurements were not frequent enough to define a seasonal pattern of freshwater discharge.

Of the 5 brooks, Adams Brook had the highest mean and the greatest maximum discharge (Table 3). Marshall and Lurvey & Heath were second in importance, while Buttermilk and China Brooks had the lowest discharge.

Mean concentrations of dissolved inorganic nutrients were generally comparable to typical values for river water entering other estuaries in Maine and elsewhere worldwide (Fig. 11, Table 4).

Relative to other sources, Marshall Brook exhibited high concentrations of nitrate + nitrite which never fell below 6 µmoles/l. In all other brooks nitrate + nitrite reached non-detectable levels during the study period. While the mean concentration of ammonia was similar in all brooks, the distribution of dissolved inorganic nitrogen (DIN) between nitrate + nitrite and ammonia varied among sources. Ammonia dominated the DIN pool in China, Buttermilk and Adams. By contrast, nitrate + nitrite was the dominant form in Marshall and Lurvey & Heath.

Total nitrogen (Fig. 11) averaged about 30 µmoles/l in all brooks excepting Adams where concentrations averaged 47µmoles/l. DIN accounted for a small proportion of the total (3 - 13%) in all but Marshall Brook where nearly half (42%) was inorganic.

Total phosphorus averaged less than 1 µmoles/l in all brooks and between 5-20% of this was inorganic. Concentrations of dissolved inorganic phosphorus were low averaging less than 0.20 µmoles/l and in most cases below 0.10 µmoles/l. Dissolved silicon (Fig. 11) was always present in substantial amounts as was dissolved organic carbon.

Of the freshwater sources, Marshall Brook accounted for most of the freshwater input of DIN, which entered the system mainly as nitrate + nitrite (Fig. 12, Table 5). This was not only a function of freshwater discharge but for the most part was due to high nutrient concentration. China Brook contributed the most dissolved inorganic phosphate (DIP) and this too was largely a function of concentration rather than discharge (Fig. 12, Table 5). While Adams Brook had a

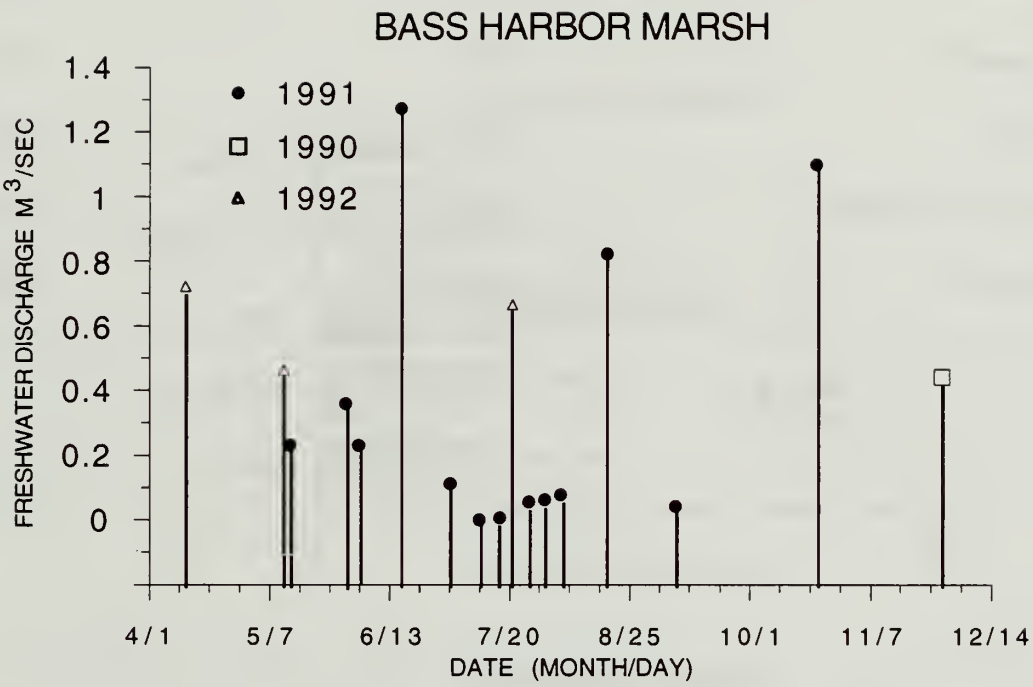


Fig. 10. Total freshwater discharge from the five brooks plotted by day.

Table 3. Mean and maximum freshwater discharge for each brook measured during the study (n=17 in each case). Minimum discharge for all brooks was 0.0 m^3/sec.

Brook	Discharge (m^3/sec)	
	Mean	Maximum
Adams	0.13	0.53
Buttermilk	0.05	0.17
China	0.05	0.18
Lurvey and Heath	0.07	0.25
Marshall	0.09	0.27

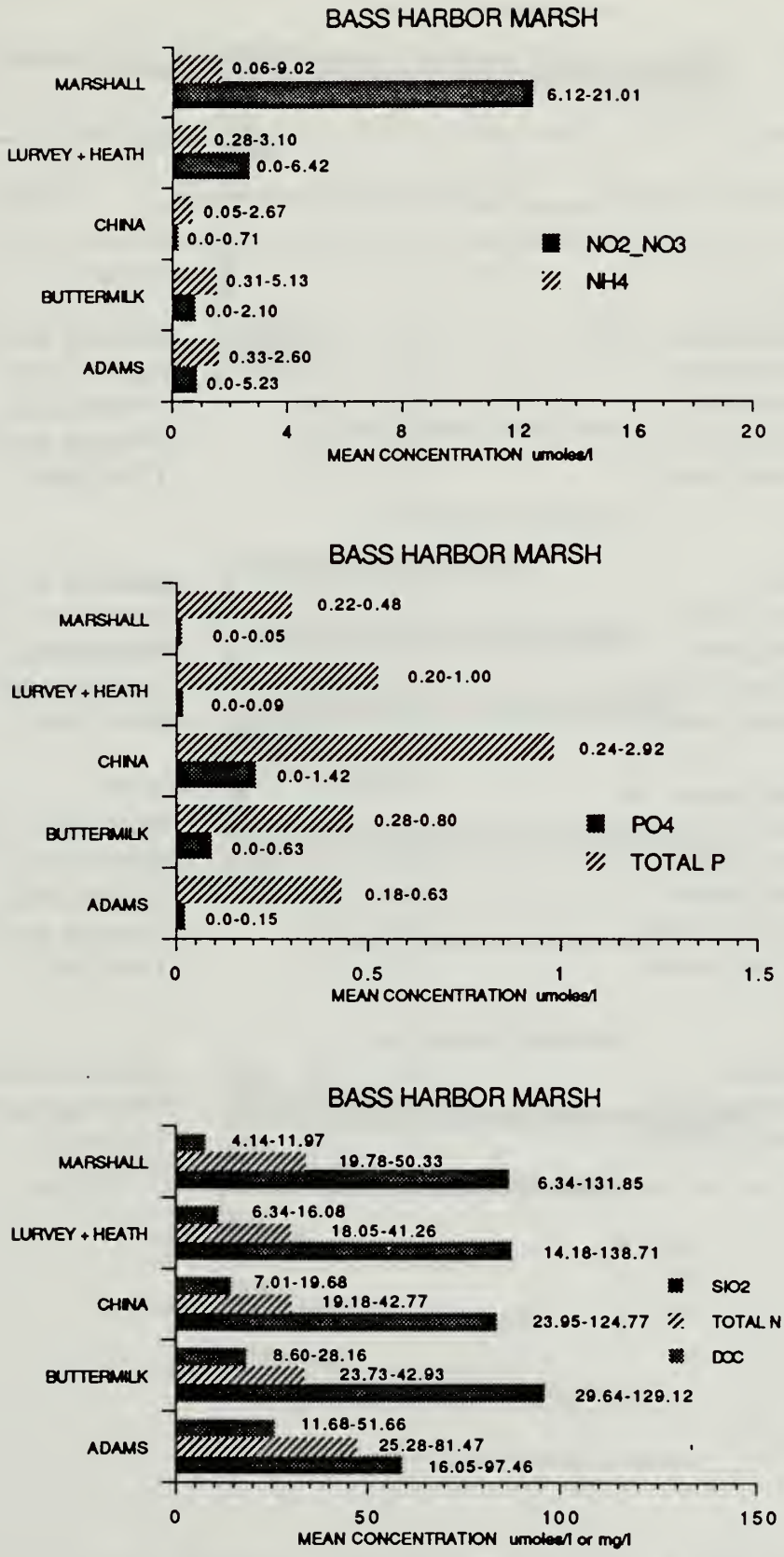


Fig. 11. Mean concentration of nutrients measured in the five freshwater brooks. n=7 in all cases excepting total N and P where n=6. Numbers above bars represent the range of concentrations measured. Units are all in umoles/l, except for DOC (mgC/l).

Table 4. Range of typical nutrient concentrations in river water.

Nutrient and Location	Concentration (µmoles/l)	Source
Ammonia		
Narragansett Bay rivers	3.0 - 158	Doering et al. 1990
Penobscot River	1.6 - 5.3	Bartlett et al. 1993
Kennebec River	1.6 - 2.6	Bartlett et al. 1993
Somes Sound rivers	0.0 - 6.8	Doering and Roman 1994
Bass Harbor Marsh	0.05 - 9.0	This Study
Nitrate		
U.S. rivers	14.3 - 63.6	Smith et al. 1987
Penobscot River	3.6 - 9.3	Bartlett et al. 1993
Kennebec River	5.7 - 12.9	Bartlett et al. 1993
Somes Sound rivers	0.0 - 7.0	Doering and Roman 1994
Bass Harbor Marsh	0.0 - 21.0	This Study
Phosphate		
U.S. rivers	1.9 - 9.1	Smith et al. 1987
Penobscot River	<0.3 - 0.3	Bartlett et al. 1993
Kennebec River	0.3 - 0.97	Bartlett et al. 1993
Somes Sound rivers	0.0 - 0.06	Doering and Roman 1994
Bass Harbor Marsh	0.0 - 1.42	This Study
Silicate		
Global rivers	49 - 649	Burton and Liss 1976
Somes Sound rivers	6 - 192	Doering and Roman 1994
Bass Harbor Marsh	6 - 139	This Study

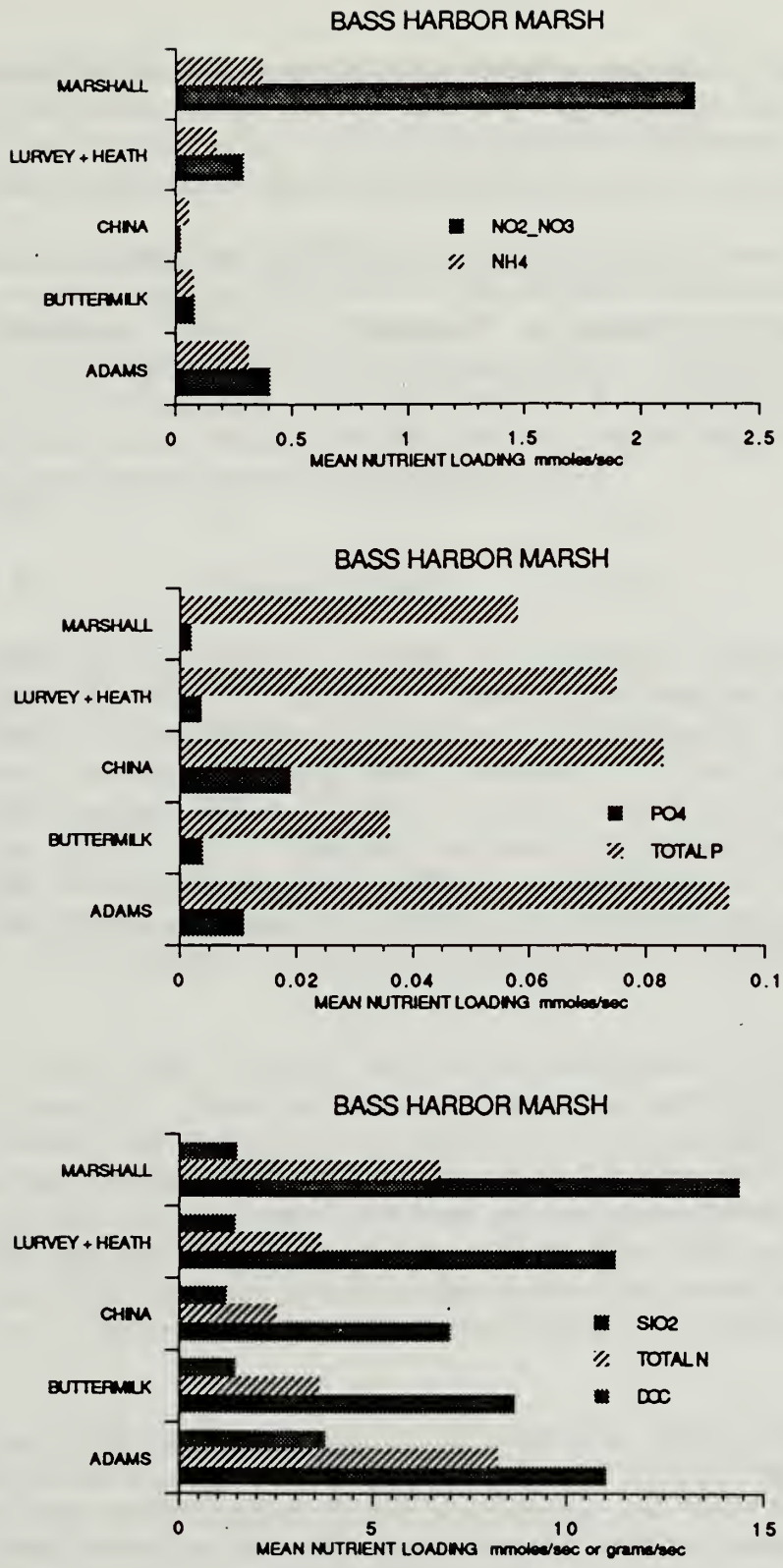


Fig. 12. Average nutrient loading (concentration x discharge) for the five freshwater brooks. Units are all mmoles/sec except DOC which is grams/sec. n=7 in all cases except for total N and P where n=6.

Table 5. Percent contribution of each source to the total nutrient load from freshwater.

	Freshwater Brook				
Nutrient	Adams	Buttermilk	China	Lurvey & Heath	Marshall
$NO_2 + NO_3$	13.4	2.7	0.8	9.7	73.5
NH_3	31.3	7.8	5.6	17.3	37.9
PO_4	27.2	10.8	47.5	8.8	5.3
SiO_2	22.0	14.8	14.0	22.5	28.7
Total N	34.1	12.4	10.4	15.1	27.9
Total P	27.1	10.4	23.7	21.7	16.5
DOC	40.0	15.5	13.1	15.5	15.8

low concentration of DIP its relatively high rate of discharge made it the second most important freshwater source for DIP and the largest source of Total P. Adams was also the dominant source of DOC and Total N while Marshall Brook was the major source of dissolved silicon (Fig. 12, Table 5).

Nitrogen to phosphorus loading ratios (Table 6) computed for each source or for the total input on each sampling date were in general well above the Redfield ratio of 16N:1P (Redfield 1958). Such high ratios suggest that the growth of aquatic plants in this water would be phosphorus limited. Interestingly, the discharge from China Brook had a DIN:DIP ratio of 4 indicating nitrogen limitation. The contribution of China Brook however was too small to affect ratios of the total input which were always greater than 16:1.

Oceanic Inputs

The estimates of Q_F, the flood tide transport of ocean water, calculated by salt balance, ranged from 31, 742 m^3 to 131,897 m^3/flood tide or from 4.0 m^3/sec to 9.77 m^3/sec (Table 7). There is no error free method of estimating the flood tide transport, however, estimates of Q_F agreed to within 8 - 73% of freshwater corrected volume changes and to within 4 - 22% of direct current meter measurements. In all there were 9 alternative estimates of the flood tide ocean water flux: 7 by freshwater corrected volume changes and 2 by direct measurement. The average deviation of Q_F from these alternative estimates was 26.5% (median = 21.6%). These comparisons suggest the error in Q_F is on the order of 25%.

The factor which most likely controls the absolute magnitude of Q_F is the duration of the flood tide. Owing in part to the sill at the mouth of the Bass Harbor Marsh estuary, the duration of the tidal cycle is not equally divided between ebb and flood. In general the tide will flood for 2-4 hours and ebb for 8-10. Thus, not only does the tidal range vary from spring to neap levels, but also the duration of the ebb and flood tides. In our study the flood tide ocean water flux (Q_F) was not related directly to tidal range (linear correlation coefficient $r=0.534$, $p>0.20$, $n=7$), but rather to duration of the flood tide ($r = 0.867$, $p< 0.02$, $n=7$; Fig. 13).

Time weighted mean nutrient concentrations of flood tide water measured at station 1 were in the same range as those for the freshwater inputs (Table 8). On average, however, the concentrations of total N, ammonia and dissolved silicon were lower in ocean water than in freshwater. Nitrate + nitrite in seawater was comparable to freshwater concentrations except those observed in Marshall Brook which were much higher. Average total P and dissolved inorganic phosphorus (DIP) were higher in seawater than in most freshwater sources withthe exception of China Brook where the concentration of total P was similar to that in seawater.

Table 6. Average nutrient loading ratios for the five freshwater brooks and loading ratios for the total input measured for each survey. NC = not calculable, ND = no data.

Source or Survey Date	DIN:DIP	Total N: Total P
Source		
Adams	63	89
Buttermilk	36	100
China	4	30
Lurvey and Heath	127	49
Marshall	1013	118
Date		
Apr. 22, 1992	53	47
May 14, 1991	2589	72
June 17, 1991	91	70
July 21, 1992	NC	94
Sept. 9, 1991	534	65
Oct. 22, 1991	129	72
Nov. 12, 1990	84	ND

Table 7. Comparison of oceanic flood tide transport (m^3) calculated by salt balance (Q_F) and freshwater corrected volume change (Q_v) and measured directly with current meters (Q_m). Percent deviation is calculated.

Date	Q_F	Q_v	$\%Dev_v$	Q_m	$\%DEV_m$
April 22, 1992	31,742	29,227	8.6		
May 15, 1991	51,527	45,932	12.2	65,730	21.6
June 18, 1991	75,587	58,379	29.5		
July 21, 1992	62,522	49,681	25.8		
Sept. 10, 1991	105,655	96,704	9.3		
Oct. 22, 1991	131,897	76,234	73.0		
Nov. 28, 1990	55,629	35,875	55.1	53,517	3.9

$$\%Dev_v = (|Q_F - Q_v|/Q_v) * 100$$

$$\%Dev_m = (|Q_F - Q_m|/Q_m) * 100$$

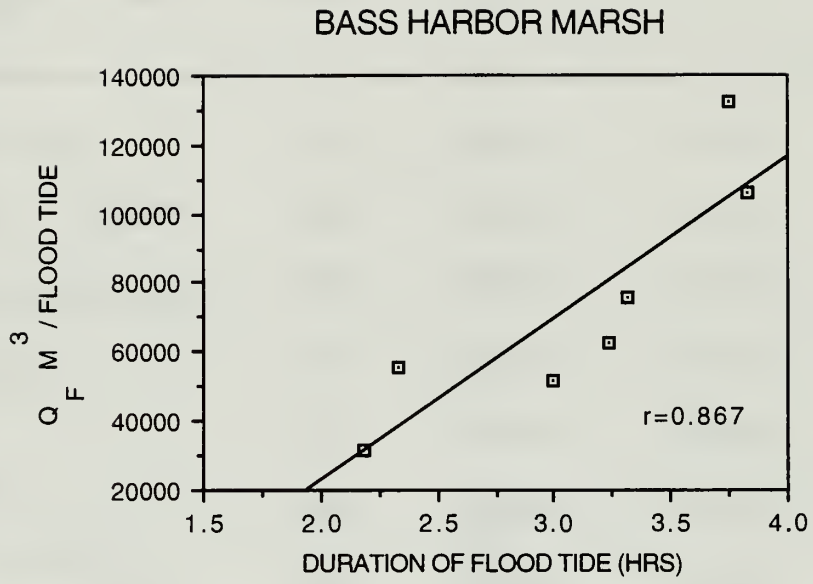


Fig. 13. Volume of oceanic flood tide (Q_F) as a function of the duration of the flood tide. Regression line is significant at the $p < 0.05$.

Table 8. Time-weighted mean nutrient concentrations of flood tide water.

Date	Nutrient Concentration(µmoles/liter)					
	Total N	Total P	NO_2-NO_3	NH_4	PO_4	S_iO_2
April 22, 1992	16.69	0.41	2.42	0.50	0.15	29.04
May 15, 1991	18.59	0.90	0.00	1.21	0.21	5.26
June 18, 1991	-	-	-	-	-	-
July 21, 1992	25.34	1.07	0.02	1.02	0.58	13.31
Sept. 10, 1991	20.04	1.00	1.01	0.07	0.80	6.82
Oct. 122, 1991	22.38	0.81	0.72	0.41	0.15	40.38
Nov. 28, 1990	-	-	5.35	0.06	0.36	28.47

The oceanic pool of DIN was not consistently dominated by ammonia or nitrate + nitrite. Like freshwater, DIN comprised a small proportion (4-18%) of the total N stock. By contrast, DIP accounted for a higher percentage of the total P pool in seawater (18-80%) than in freshwater (5-20%).

Comparison of Oceanic and Freshwater Inputs

The Bass Harbor Marsh estuary is connected to the sea via a narrow passage through a causeway. Water from the ocean enters only on the flood tide while freshwater from brooks can escape only during ebb tide. Thus, volume changes on the flood tide arise both from the tidal flux of seawater and the accumulation of freshwater. The oceanic transport of seawater into the system far outweighed the volume transport of freshwater entering during the flood tide. The freshwater volume accumulating on the flood tide averaged 10.5% (range 0.5-20%) of the oceanic transport, and thus, the latter accounted for most of the tidal volume change in the system.

Because of the narrow constriction at its mouth, nutrients and other material from the ocean can be transported into the marsh only on the flood tide. Since there is one flood tide every twelve hours, the oceanic nutrient input is approximately comparable to 12 hours of freshwater input. As a statistical yardstick, to judge the dominance of one source over the other we have used the Wilcoxon Matched-Pairs Signed-Ranks test (Snedecor and Cochran 1967) which is a non-parametric equivalent of a paired t-test. Pairing was by date. Both the ocean and freshwater brooks contributed significantly to the input of dissolved inorganic nitrogen: neither source dominated (Fig. 14, Wilcoxon Matched-Pairs Signed-Ranks test $T=11$, $p>0.10$, $n=6$ pairs). By contrast the input of dissolved inorganic phosphorus was dominated by the oceanic source (Fig. 14, Wilcoxon Matched-Pairs Signed-Ranks test $T=1$, $p<0.05$, $n=6$ pairs). Essentially the same pattern was obtained for total nitrogen and total phosphorus but because there were fewer data this statement can be made with less statistical certainty. The results of the Matched-Pairs Signed-Ranks test were: $T=2$, $p>0.10$ $n=5$ pairs per total N and $T=1$, $p<0.10$ $n=5$ pairs per total P. Loading of dissolved silicon (Fig. 14) to the marsh showed the same pattern as dissolved inorganic nitrogen with both sources contributing equally (Wilcoxon Matched-Pairs Signed-Ranks Test $T=8$, $p>0.10$, $n=6$ pairs).

While the relative magnitudes of oceanic and freshwater inputs in part determine the availability of nutrients to aquatic vegetation in the marsh, the composition of the inputs is also important. While DIN and DIP are readily available to plants, organically or otherwise bound forms must be remineralized before becoming available. The ratio of DIN or DIP to total N or P serves as a measure of nutrient availability. DIN always accounted for less than half the total N load from both sources (Fig. 15). The proportion of DIN in freshwater was consistently higher

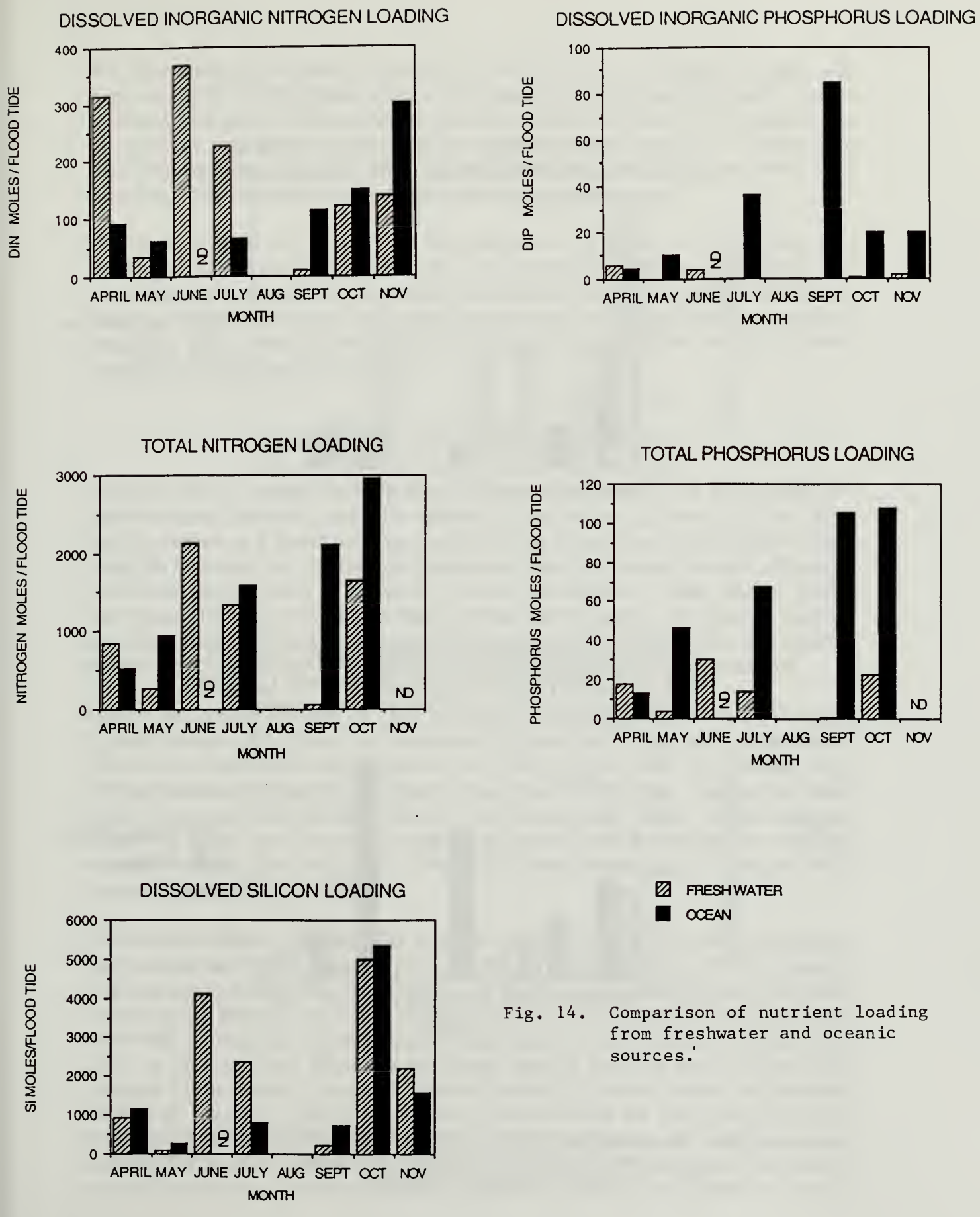
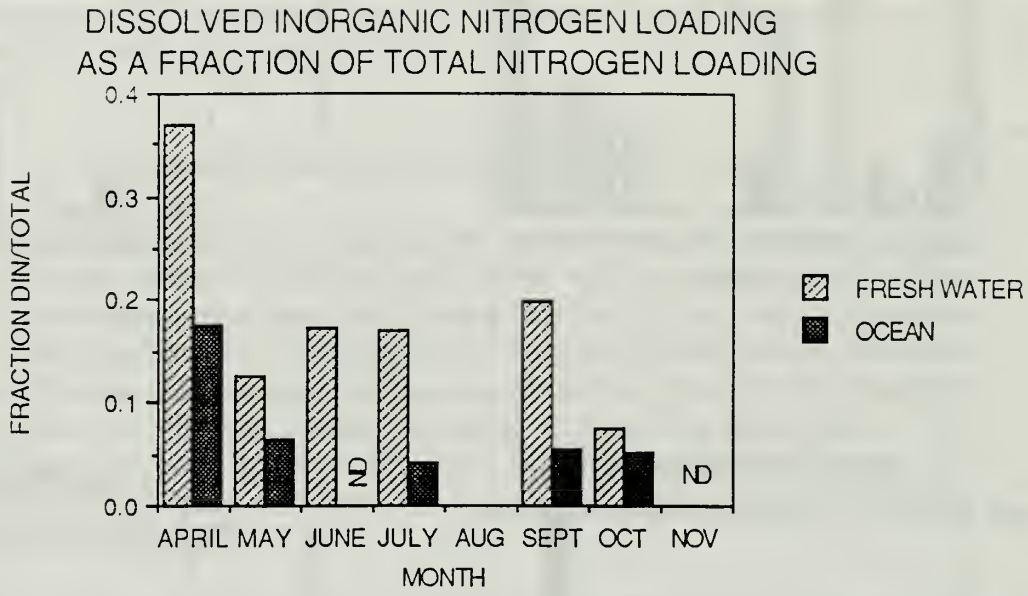


Fig. 14. Comparison of nutrient loading from freshwater and oceanic sources.



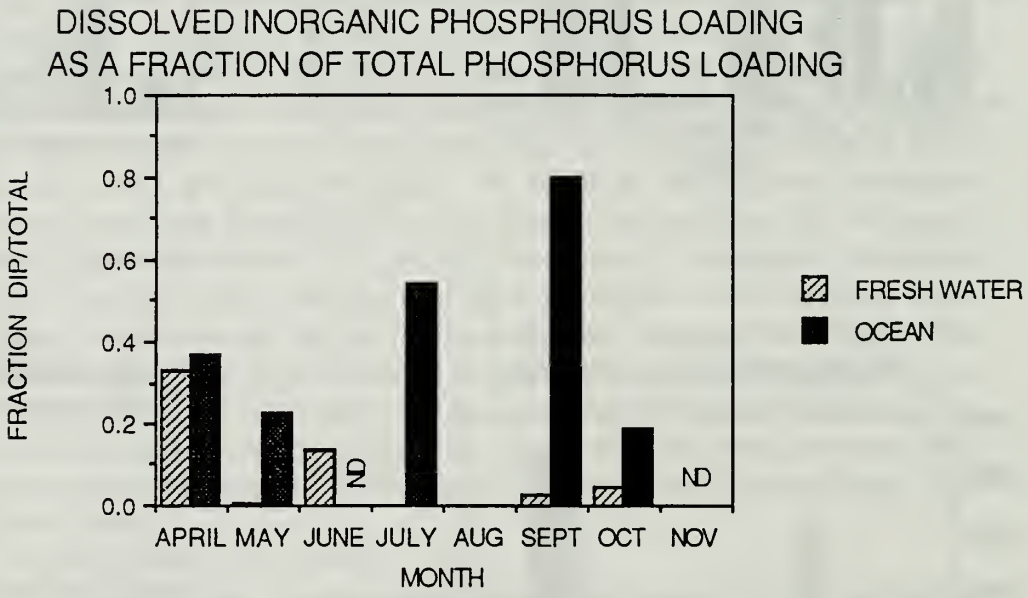


Fig. 15. Composition of the freshwater and oceanic nutrient loads of total nitrogen and phosphorus expressed as the inorganic fraction.

than in saltwater but never by more than 20% (Fig. 15). Although nitrogen was more available in freshwater than in saltwater, the nitrogen from both sources was mostly organic in form and not readily available to plants. As expected, the phosphorus load from the ocean had a higher proportion of DIP (18-80%) than that from freshwater (0-33%) (Fig. 15) suggesting that the total phosphorus load from the ocean was more available than that from freshwater.

The ratio of total N to total P in the nutrient load from the ocean was, like freshwater, above the Redfield ratio of 16 to 1 (Table 9). Because most of the total N was bound and much of the total P was mineralized, DIN to DIP ratios were lower and generally below 16, suggesting nitrogen limitation of plant growth in seawater. This contrasts with DIN to DIP ratios in freshwater which indicated phosphorus limitation (see Table 6).

Distribution of Nutrients in the Estuary

Salinity versus property plots provide a convenient method of visualizing the distribution of nutrients and other material in an estuary (Burton and Liss 1976). Salinity serves as a tracer for ocean water and as it becomes diluted below ocean strength indicates the relative proportions of fresh and ocean water. Although occasional stratification of the water column was observed, Bass Harbor Marsh was generally well-mixed especially in the lower basin. In general, salinity increased from the head to the mouth of the estuary (Table 10). For this system, salinity versus property plots also imply the spatial distribution of material.

Significant concentrations of DIN occurred throughout the estuary although highest values were found in freshwater (Figure 16a). The same pattern was obtained for both ammonia and nitrate+nitrite (Fig. 16b, 16c). By contrast, high concentrations of dissolved inorganic phosphate (DIP) were observed in more saline waters at the seaward end of the system (Fig. 16d). Total nitrogen, dissolved silicon, and dissolved organic carbon all tended to decrease as salinity increased (Figs. 16c, 16f, 16g). Like DIP, total phosphorus increased with increasing salinity (Fig. 16h).

The concentrations of organically or otherwise bound nitrogen and phosphorus can be calculated by difference between total N or P and DIN or DIP. Although this fraction is termed "organic", especially in the case of phosphorus, it includes an inorganic fraction bound to suspended sediment particles (Froelich 1988). Like total N, organic N concentrations decreased with increasing salinity (Fig. 16i). In fact the two plots are strikingly similar because much of the total nitrogen in the estuary is bound. Most of the total N concentrations fall between 15 and 50 µmoles/l, while most DIN concentrations are below 10 µmoles/l. Organic or otherwise bound phosphorus (Fig. 16j) increases with increasing salinity like total P. This similar pattern is perhaps surprising given that total P in the oceanic input is proportionately higher in DIP than the freshwater input.

Table 9. Nutrient loading ratios of the oceanic input on the flood tide.

Date	DIN:DIP	Total N : Total P
April 22, 1992	19	41
May 15, 1991	5.7	20
June 18, 1991	-	-
July 21, 1992	1.8	24
Sept. 10, 1991	1.4	20
Oct. 122, 1991	7.5	28
Nov. 28, 1990	15.0	-

Table 10. Mean and range of salinity (ppt) observed at each station over the seven synoptic surveys. See Fig. 7 for location of sample stations.

	Salinity (ppt)		
Station	Mean	Min	Max
1	22.29	2.35	31.87
2	20.51	1.05	31.74
3	15.61	1.01	31.65
4	17.00	0.41	31.65
5	8.15	0.05	29.44
6	6.94	0.04	25.84
7	6.95	0.03	21.77
8	6.56	0.017	22.46
9	1.13	0.014	9.86
A1	7.96	0.165	29.72
A2	14.54	0.15	30.68

Fig. 16 a.

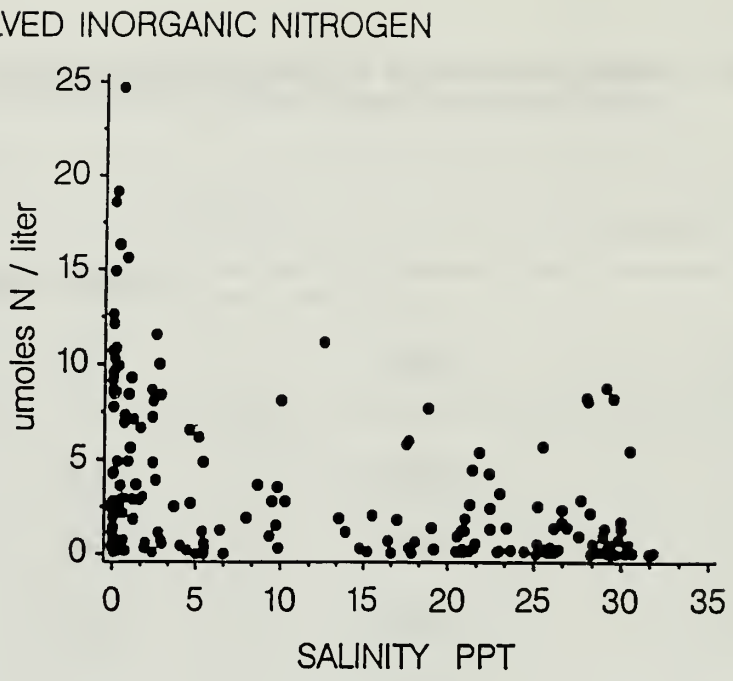


Fig. 16b.

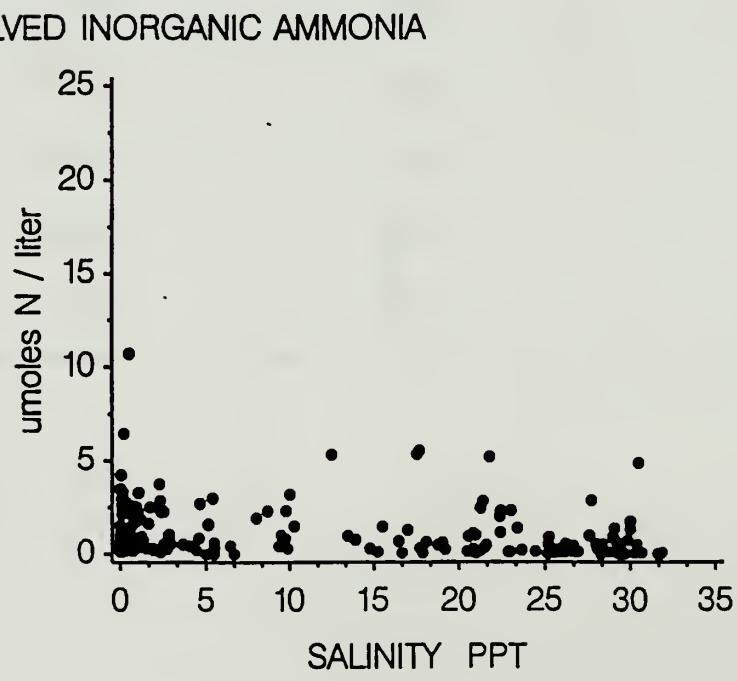


Fig. 16. Salinity vs property plots (a-j)

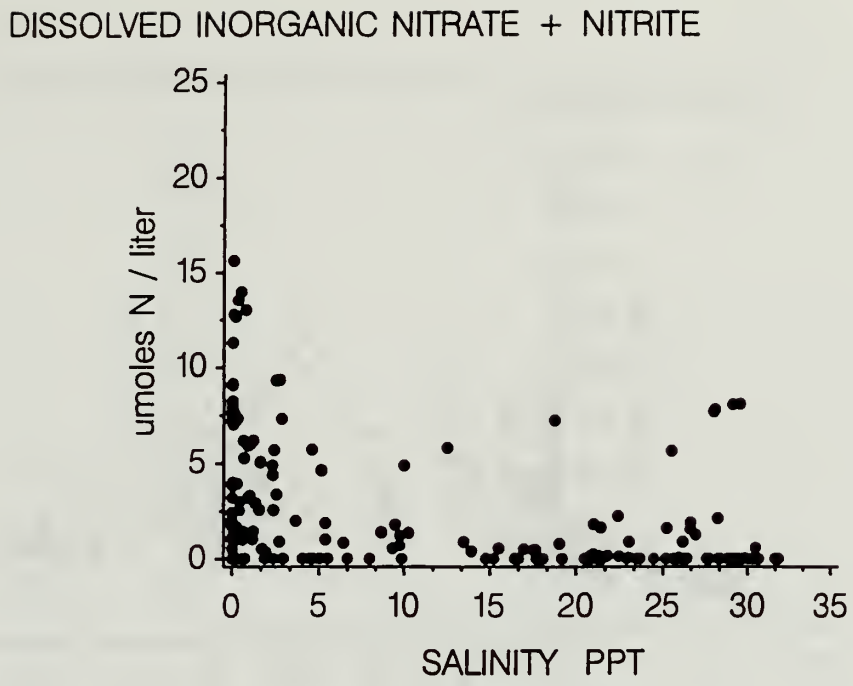


Fig. 16c.

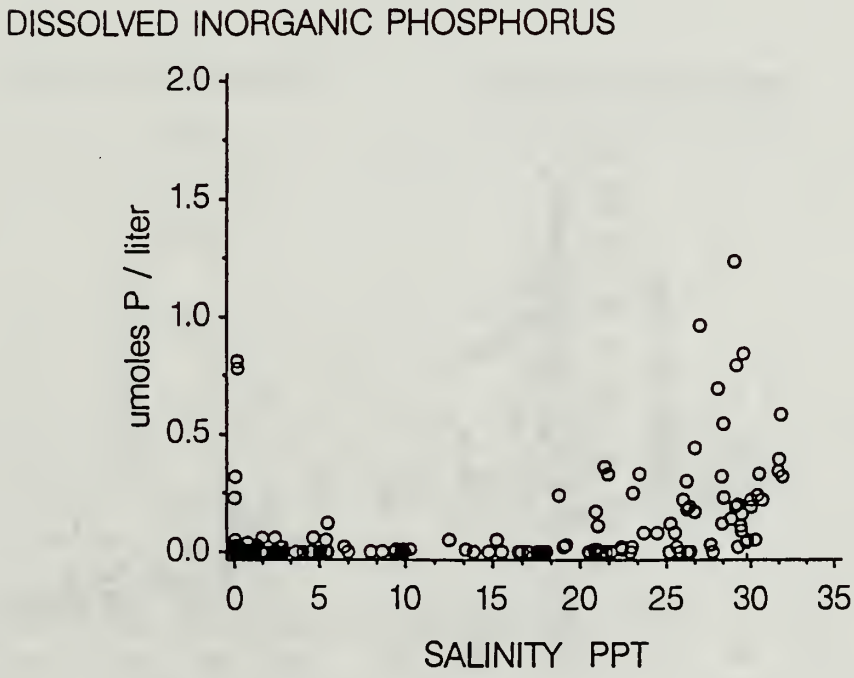


Fig. 16d.

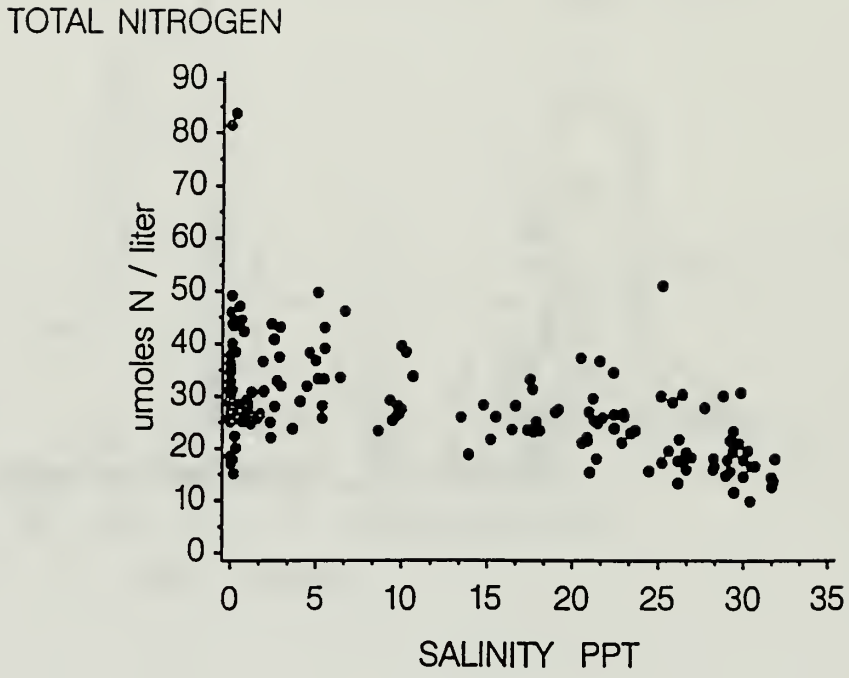


Fig. 16e.

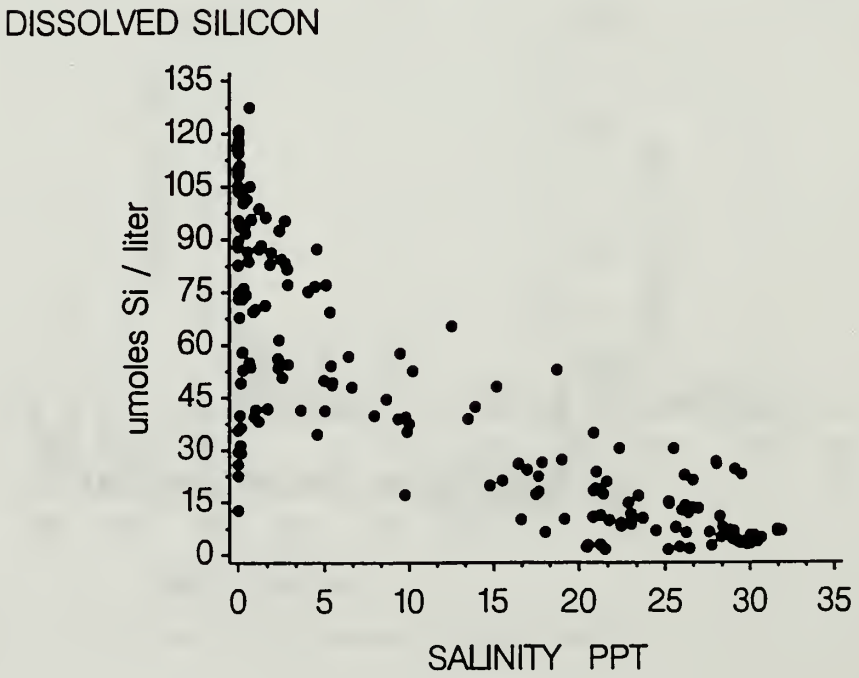


Fig. 16f.

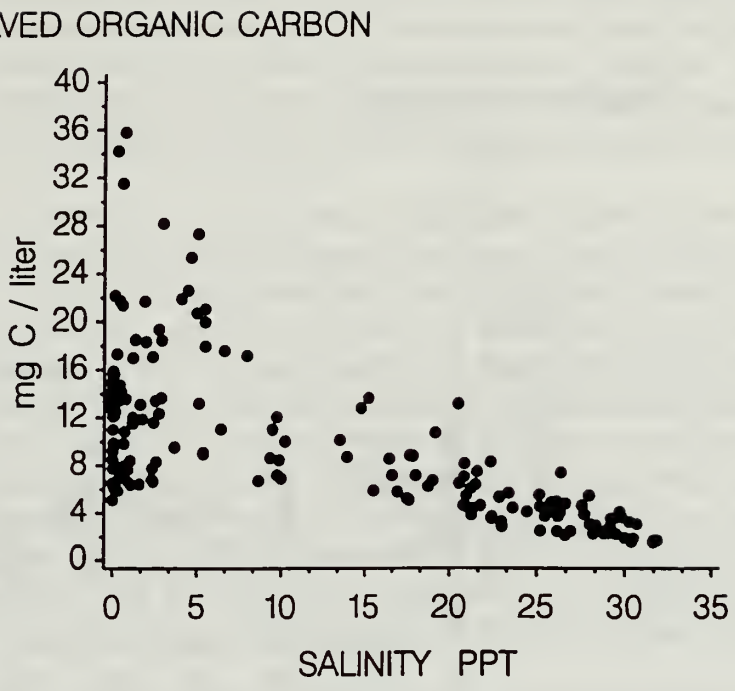


Fig. 16g.

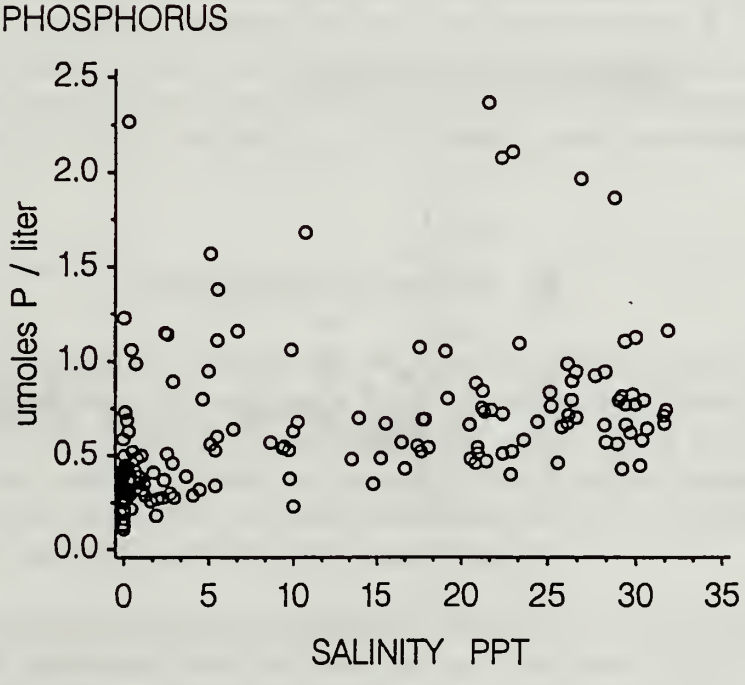


Fig. 16h.

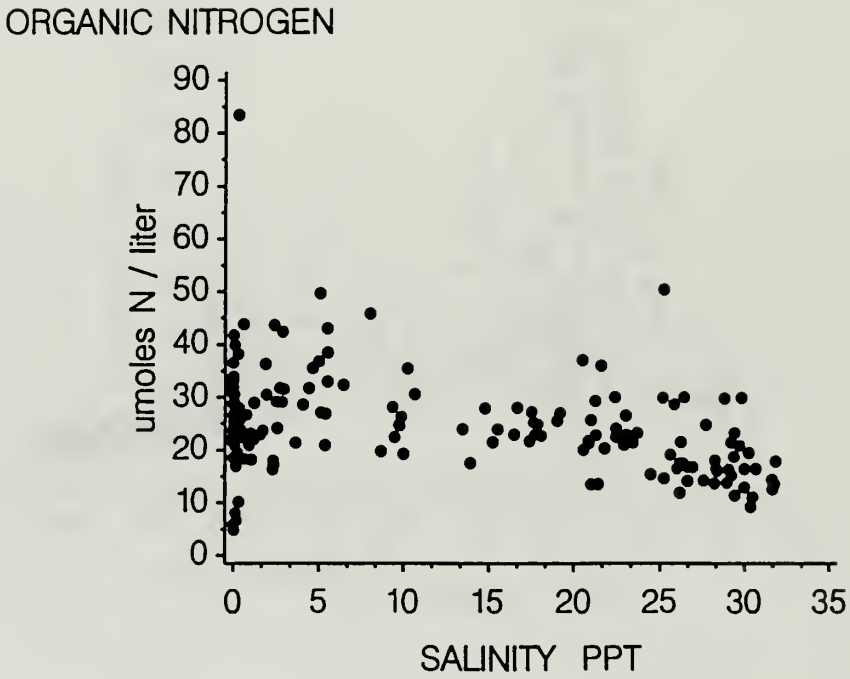


Fig. 16i.

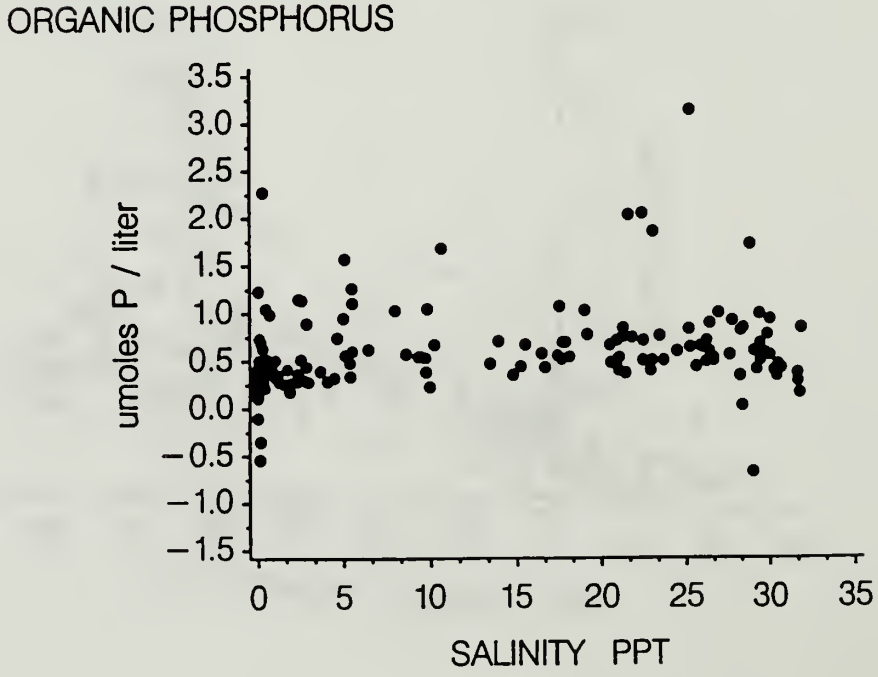


Fig. 16j.

If the composition of total P changes from the fresh to the salt water end of the estuary then the concentration of total P should increase faster with increasing salinity than the concentrations of organic P. The slopes for linear regressions of concentration on salinity were for total P, 0.015 µmoles/l, and for organic P, 0.008 µmoles/l. Although the difference between them is in the expected direction they were not statistically different (95% confidence intervals overlap).

Qualitatively, the distribution of nutrients in the Bass Harbor Marsh estuary reflects differences in concentration between freshwater and oceanic sources. The concentrations of total N, ammonia and dissolved silicon were higher in freshwater than in seawater and this difference is reflected in the estuary by decreasing concentrations with increasing salinity. The high levels of nitrate + nitrite in Marshall Brook may account for the similar pattern observed for this nutrient in the estuary. Both DIP and total P were more concentrated in seawater than in freshwater. Thus, in the estuary concentrations increase with increasing salinity. The differences in distribution of DIN and DIP within the estuary on average result in high (>16:1) DIN/DIP ratios at the head of the estuary and low ratios (<16:1) at its mouth (Fig. 17). The ratio approaches the Redfield ratio (16:1) at stations 3 and 4 (the point where the DIN and DIP curves intersect on Fig. 17).

Results of the STELLA steady state model runs to predict the distribution of nutrients in the estuary given an alteration of either freshwater nutrient loading or oceanic nutrient loading are presented in Table 11 and Fig. 18. The model provides good agreement with the observed data especially with regard to the DIP data (Table 11). If DIN concentration from Marshall Brook were to be reduced to the average concentration of DIN entering from the more pristine brooks (i.e., Lurvey/Heath, China, Buttermilk), it is predicted that the N:P ratio of 16:1 would shift upstream, toward the brackishwater station 6. With an increase in DIN loading from the ocean by 50%, perhaps simulating a dramatic acceleration of development along the Harbor shoreline, there does not appear to be a substantial change in the distribution of DIN throughout the estuary (Table 11, Fig. 18).

Steady State Box Model

The Q's and E's calculated for each of the 7 synoptic surveys were all in the expected direction (Table 12). Q_1 represents the freshwater input from Marshall, China, Lurvey and Heath and Buttermilk Brooks, while Q_5 is equal to the freshwater input from Adams Brooks. In general, non-advective transport (E's) decreased from the seaward end of the system to the head, reflecting the observed decrease in salinity from mouth to head (Table 12).

The residence time of salt in the estuary was short, ranging from 0.5 days in June to nearly 3 days in September, and proportional to freshwater input (Fig. 19). The relationship between river discharge and residence time of salt in the system

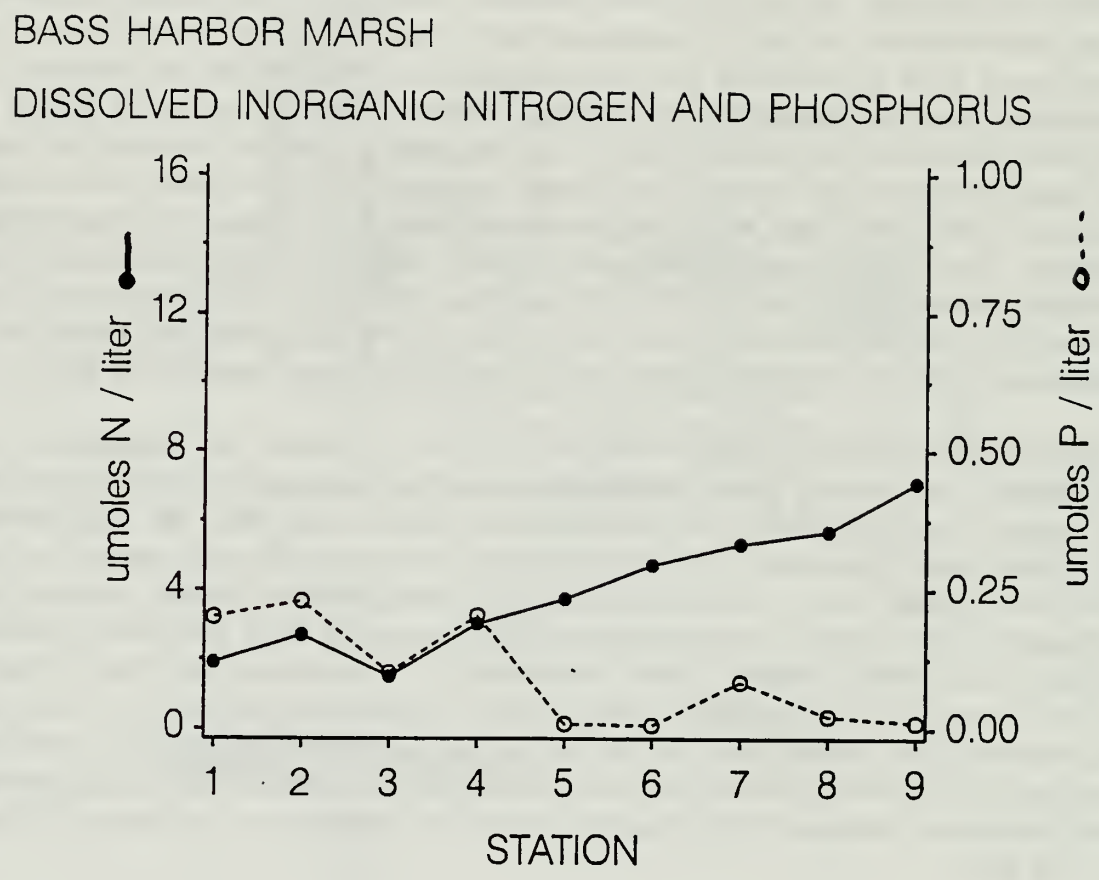


Fig. 17. Average DIN and DIP concentration averaged over the growing season for the 9 sample stations. Note that the intersection of the DIN and DIP plots represents an N:P ratio of 16:1.

Table 11. Predictions from STELLA Model runs of average (n=7 sample dates) DIN concentrations in four segments of the Bass Harbor Marsh from freshwater (segment 1) to the mouth (segment 4). Observed data are from the actual sample events. Model runs are presented for present conditions, decrease of Marshall Brook DIN loading to levels equivalent to the other un-impacted brooks, and increase DIN loading from the ocean by 50%.

SEG	OBSERVED (µM/L)		MODEL PREDICTIONS (µM/L)					
	Present		Present		Dec. Marshall		Inc. Ocean	
	DIN	DIP	DIN	DIP	DIN	DIP	DIN	DIP
1	4.78	0.02	6.06	0.09	1.67	0.09	6.13	0.09
2	2.75	0.10	4.47	0.13	1.64	0.13	4.82	0.13
3	2.43	0.22	2.77	0.18	1.84	0.18	3.50	0.18
4	2.36	0.25	2.31	0.19	1.94	0.19	3.21	0.19

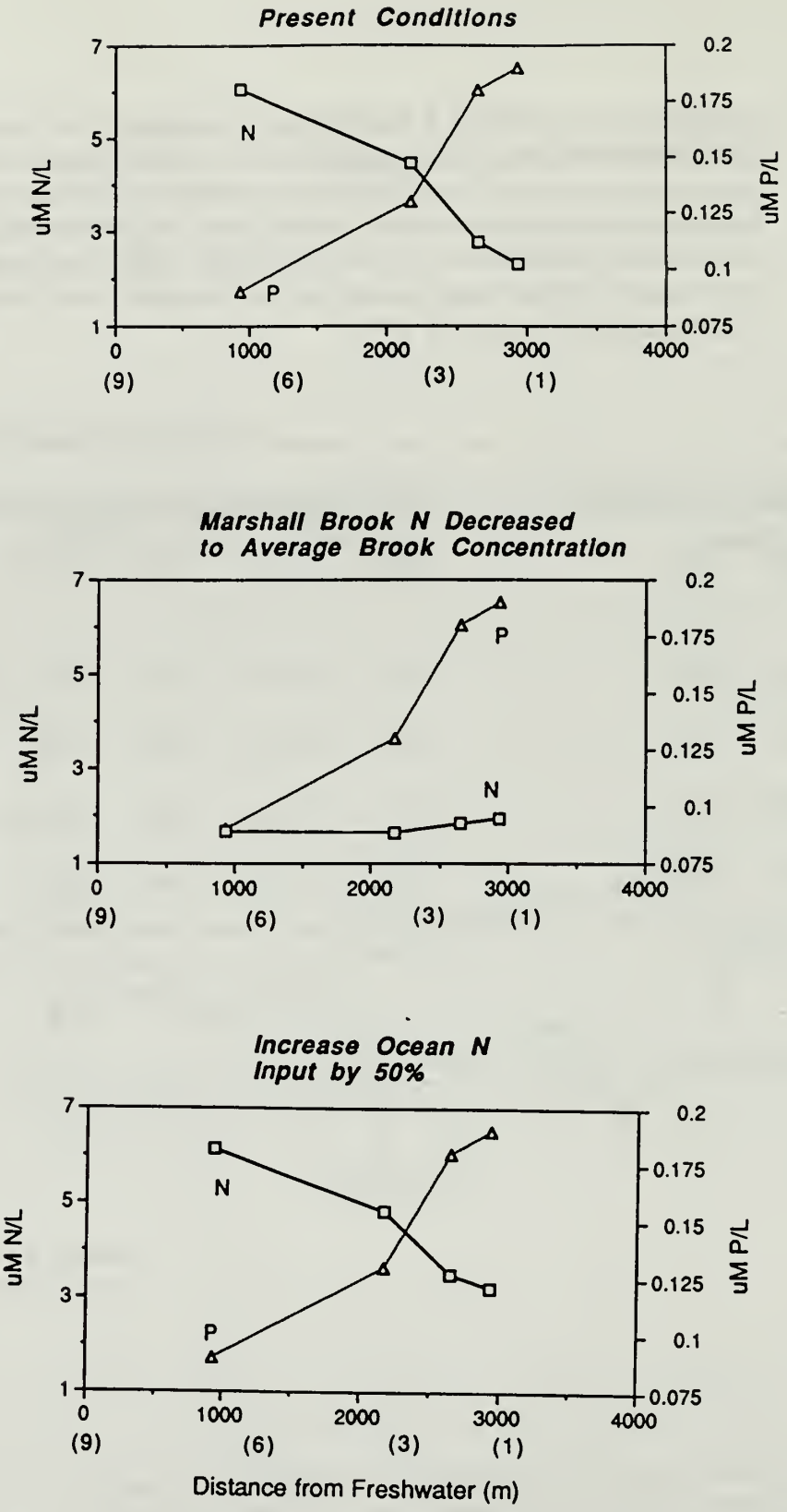


Fig. 18. Predicted DIN and DIP concentrations throughout the estuary from STELLA modelling. Model runs are for present conditions, decreasing DIN input from Marshall Brook, and increasing DIN from the ocean. A ratio of 16:1 is at the intersection of the plots. With distance from the freshwater end, station number is indicated in parentheses.

Table 12. Advective (Q) and non-advective (E) exchanges (m^3/sec) calculated from the steady state box model for each of 7 synoptic surveys.

	April 22	May 15	June 18	July 21	Sept. 10	Oct. 22	Nov. 28
Q_1	0.578	0.160	0.746	0.538	0.040	0.781	0.340
E_1	0.022	0.278	0.576	0.012	0.131	0.045	0.008
Q_2	0.578	0.160	0.746	0.538	0.040	0.781	0.340
E_2	0.394	1.234	1.864	0.370	0.582	0.871	0.223
Q_3	0.723	0.230	1.273	0.665	0.040	1.096	0.440
E_3	3.228	18.250	7.793	2.624	6.720	37.144	1.444
Q_4	0.723	0.230	1.273	0.665	0.040	1.096	0.440
E_4	2.538	21.542	327.083	33.182	143.663	739.802	2.228
Q_5	0.145	0.070	0.527	0.127	0.000	0.315	0.100
E_5	0.739	2.000	1.782	0.082	0.000	0.275	0.127

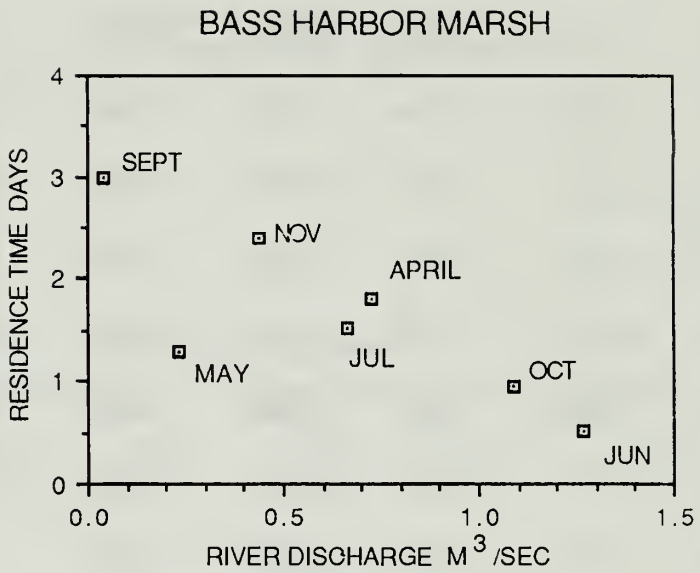


Fig. 19. Residence time (days) of salt in the Bass Harbor Marsh estuary as a function of freshwater input from brooks. Regression is significant at $p < 0.05$.

was linear and statistically significant ($r=0.812$, $p<0.05$) even with the May point which appears anonymously low (Fig. 19). The data suggest that if no freshwater entered the estuary, the tide alone could flush the system in slightly over three days.

The relationships between predicted and observed segmental nutrient concentrations are depicted in Fig. 20. Functional regression slopes were all equivalent to 1.0 (95% confidence intervals overlapped 1.0) while intercepts were not different from zero (95% confidence intervals overlapped 0.0, Table 13). These results indicate that in general nutrient concentrations in Bass Harbor Marsh are a function of inputs and mixing. Although statistically different from 1.0, the comparatively large slope for ammonia suggests potential loss from the estuary while the comparatively low slope for phosphate suggests addition.

Aside from dissolved silicon, total N and organic N which had high R-squares, the variability in predicted concentrations explained by observed concentrations ranged from 19-74% (Table 13). Thus, while the central tendency of the relationship between predicted and observed concentrations was 1:1, there was considerable scatter around it.

Chlorophyll a

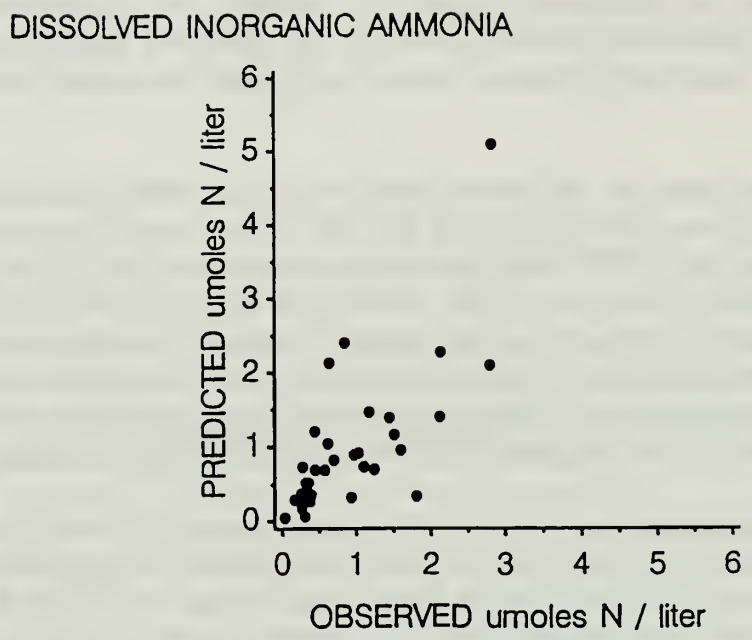
Detectable phytoplankton biomass, as measured by chlorophyll a, occurred over the entire salinity range (Fig. 21). The distribution of chlorophyll a did not vary as a function of salinity indicating that 1) neither of the endmembers (freshwater or ocean) dominated as sources and 2) that accumulation of biomass was an in situ process.

Seasonally, phytoplankton biomass fluctuated inversely with biomass of submerged aquatic vegetation (SAV). At stations 3 and 9 (Fig. 22) chlorophyll a in the water column peaked after the major period of SAV production in early summer. At station 6, the mid-summer peak in *Ruppia* biomass was both preceded and followed by peaks in phytoplankton biomass. This apparent succession of phytoplankton and SAV biomass suggests competition for some commonly required resource such as light or nutrients.

DISCUSSION

Some Preliminary Considerations

Before considering the ramifications of the study it is worthwhile to consider the limitations of the data and the constraints consequently imposed on results and conclusions. The picture of water quality during the growing season, presented



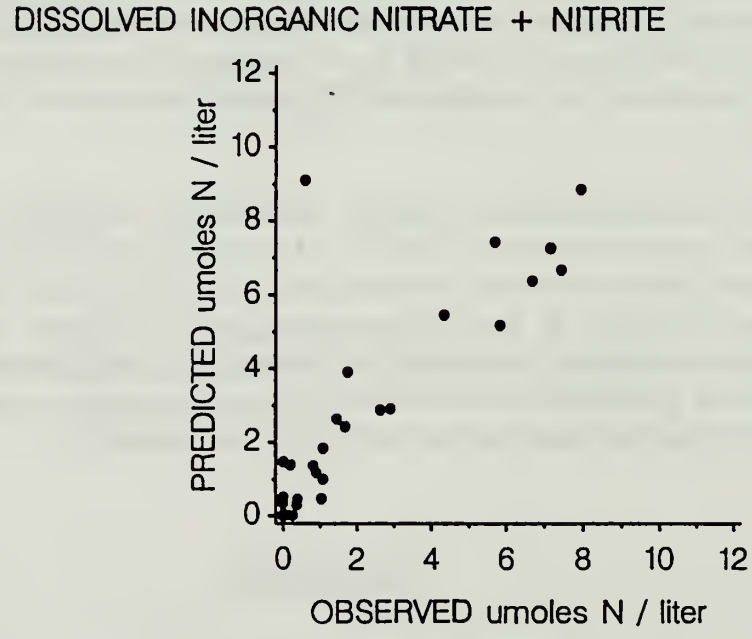
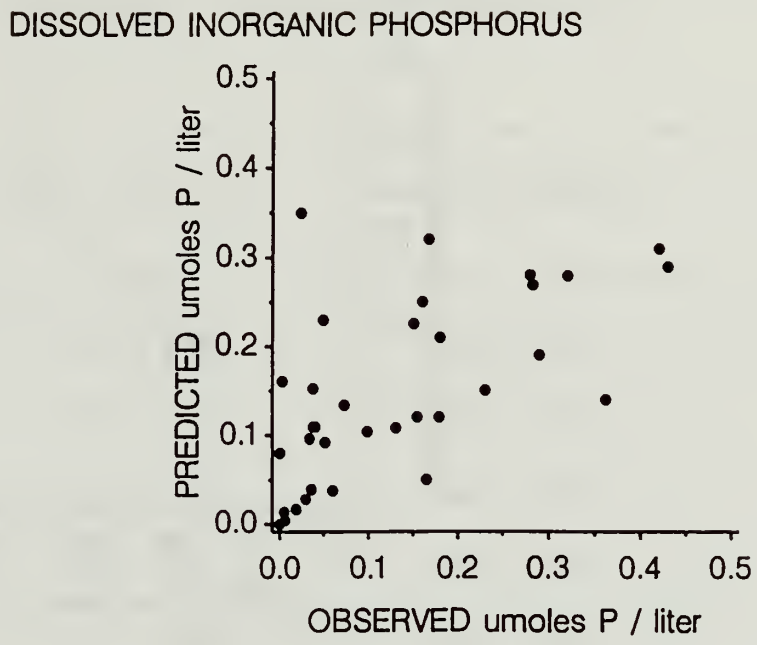


Fig. 20. Predicted (steady state box model) vs observed concentration of nutrients. Data combined for all sample surveys.



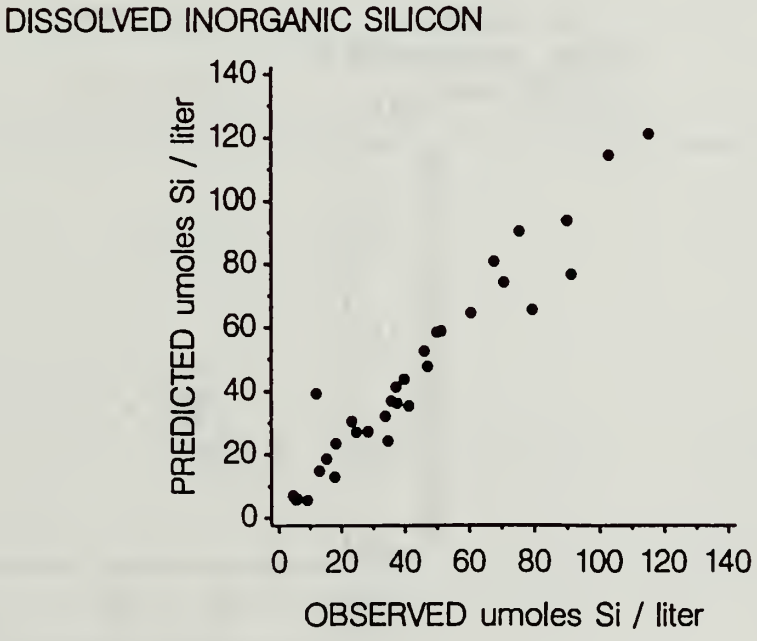
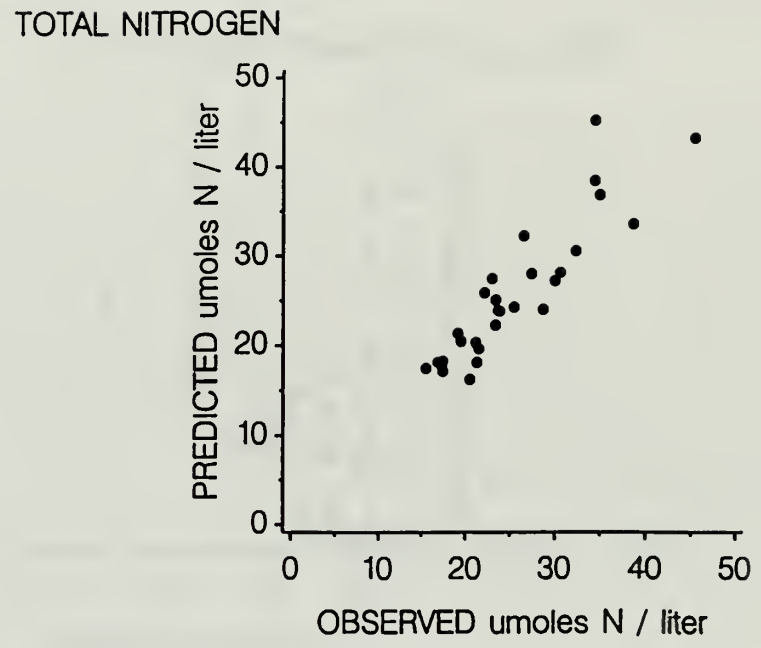


Fig. 20. Continued.



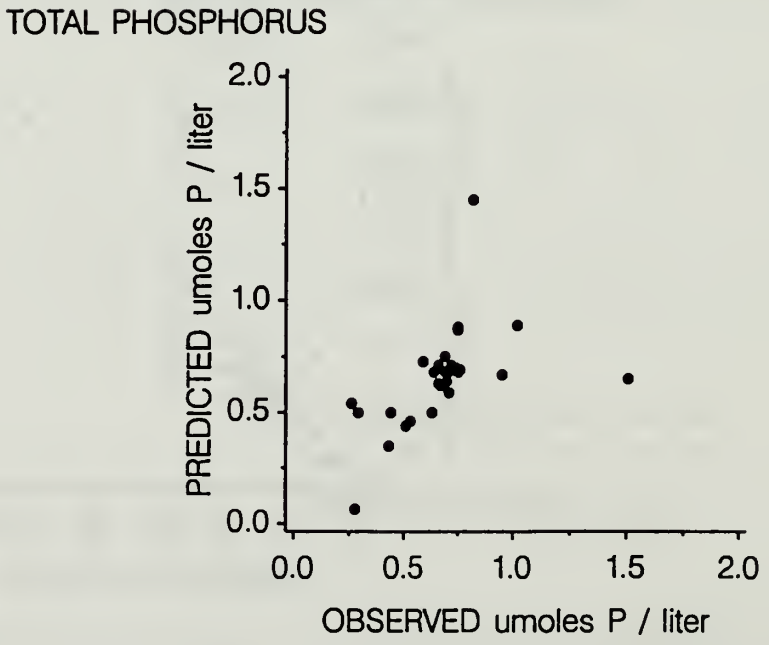


Fig. 20. Continued.

Table 13. Summary of functional regressions of predicted (g) on observed (x) nutrient concentrations. Predicted concentrations calculated from a steady state box model with 5 segments. n=34 in all cases except total N and organic N where n=29.

Nutrient	Slope ± (95% CI)	Intercept ± (95% CI)	R^2
$NO_2 + NO_3$	1.13 ± 0.22	0.39 ± 0.68	0.709
NH_4	1.31 ± 0.33	-0.18 ± 0.39	0.504
DIN	1.11 ± 0.21	0.42 ± 0.83	0.735
PO_4	0.80 ± 0.23	0.04 ± 0.83	0.378
Si	1.04 ± 0.009	1.94 ± 4.74	0.938
Total N	1.15 ± 0.18	-3.58 ± 4.84	0.813
Total P	0.95 ± 0.32	0.02 ± 0.23	0.250
Organic N	0.948 ± 0.14	0.853± 3.42	0.862
Organic P	0.926± 0.33	0.006± 0.19	0.185

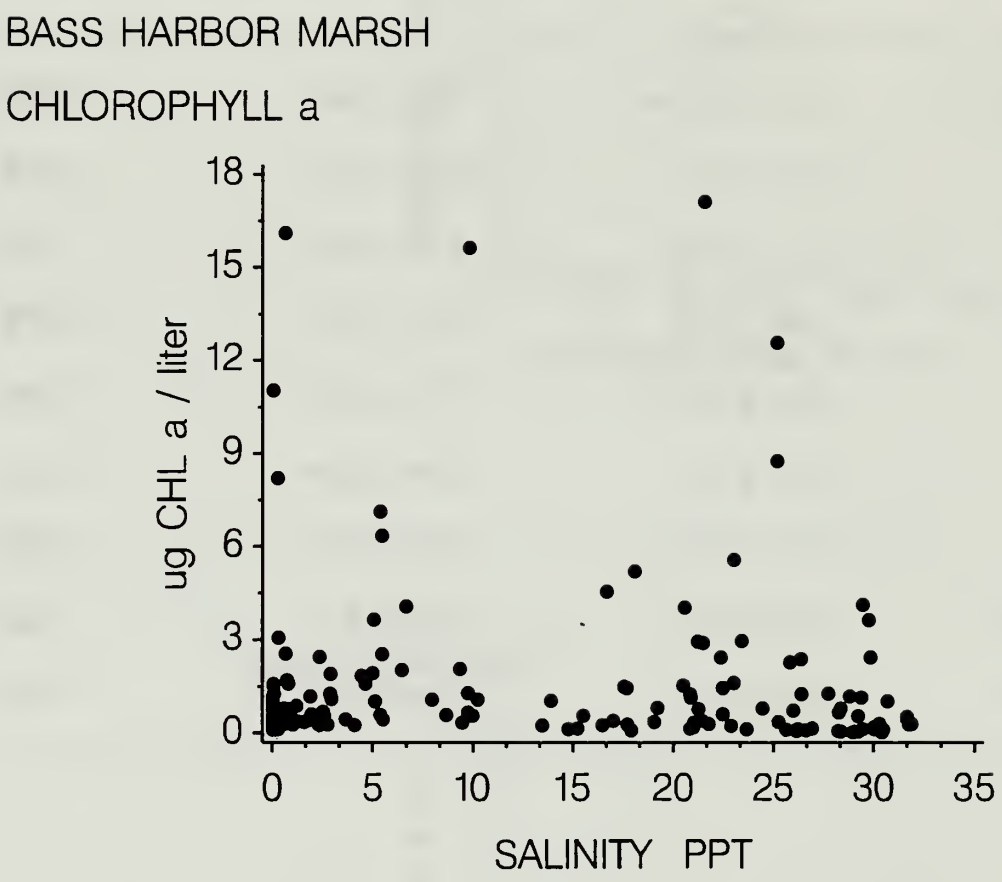
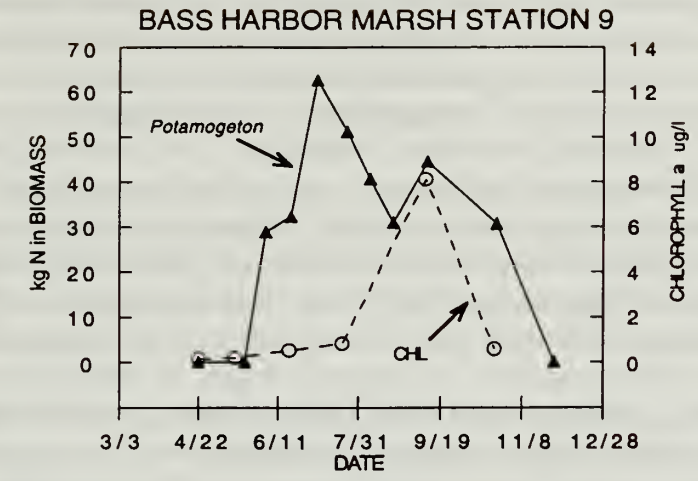
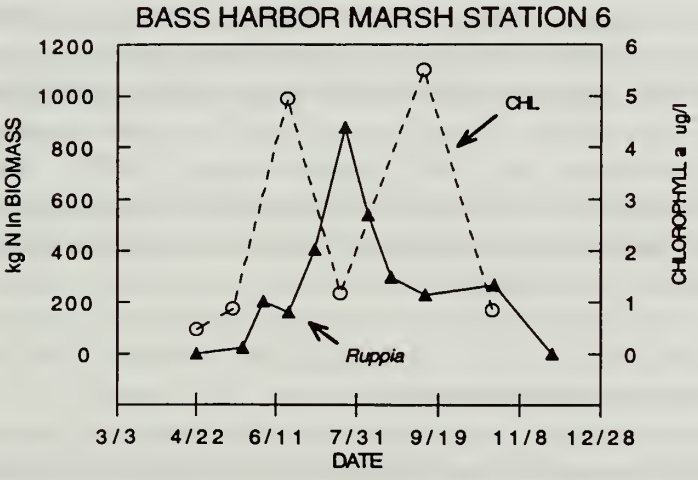


Fig. 21. Concentration of chlorophyll a as a function of salinity.





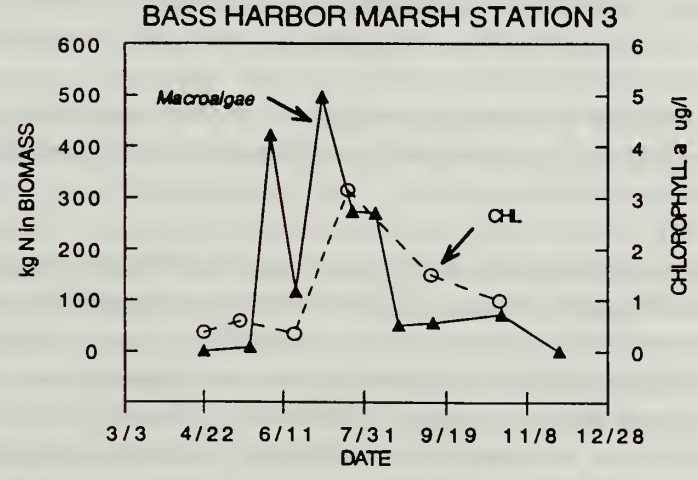


Fig. 22. Concentration of chlorophyll a in the water column and biomass of aquatic vegetation at stations 9, 6, and 3.

here, comprises a composite of seven surveys occurring in three different years (1990, 1991, 1992). Thus apparent seasonal variation may be due to interannual variability. Results and conclusions which rely only on data from the surveys will not be affected by this confounding of variability (e.g. relative magnitude of freshwater and oceanic inputs). However, comparisons of water quality with other data, most importantly submerged aquatic vegetation and macroalgae biomass, will be compromised in so far as the three annual cycles from which the water quality data were drawn diverge from each other. All vegetation biomass data and all but three water quality surveys (Nov. 1990, April, July 1992) were gathered in 1991. In November 1990 and April 1992 SAV biomass was nil in the system and based on our observations this pattern is qualitatively repeatable from year to year. For water quality we regard these as seasonably representative endpoints of the growing season. The July 1992 survey is the only water quality datum whose relationship to vegetation biomass in the estuary remains questionable and this should be kept in mind when considering results.

The data and conclusions are also temporally limited to the growing season (April-November) of submerged aquatic vegetation in the Bass Harbor Marsh estuary. Evidence suggests that for the mainstem of the Chesapeake Bay and several subestuaries large nutrient loads delivered during the winter-spring are remineralized to support plankton productivity during the subsequent summer (Kemp and Boynton, 1984; Malone et al. 1988; Magnien et al. 1992). Such seasonal lags between nutrient delivery and fixation into organic matter are not addressed by this study. Bass Harbor Marsh is generally frozen until mid-March making winter field surveys nearly impossible.

Nutrient Concentrations

Nutrient concentrations in estuaries are influenced by both external and internal factors and processes. External factors include inputs from rivers, rainfall, groundwater and atmospheric deposition. Internal processes include biological utilization and remineralization, geochemical reactions, and physical settling and resuspension. The relative importance of external and internal factors in establishing concentrations depends on the ability of the estuary to retain nutrients on time scales sufficient for internal processes to act (Officer 1980) and on the relative magnitudes of the rates of external inputs and internal processes (Kelly et al. 1985).

We have used a box model to predict nutrient concentrations which should result from external freshwater and oceanic inputs. These have been compared to concentrations actually observed in order to assess the influence of internal processes. This approach contrasts external inputs with the net effects of internal processes. If internal loss processes balance internal addition processes, their net effect will be nil and concentrations will appear controlled by external inputs. The approach is not well suited for identifying specific internal processes or their

rates. As in this study, this deficiency is at least partly relieved by measuring as many forms of a constituent as possible. For example a tight coupling between nitrification of ammonia and loss of nitrate to the sediments to fuel denitrification may result in no discernible change in nitrate concentration, but may result in lower than expected concentrations of ammonia or total nitrogen.

The agreement between predicted and observed concentrations was judged by functional regression (Table 13). The regressions were computed from the entire data set which includes spatial (5 segments) and temporal (7 dates) variability. These regressions thus represent average conditions over the whole estuary during the growing season of SAV (April-November).

The results of the steady state box model indicate that external inputs from freshwater brooks and the ocean establish nutrient concentrations in the Bass Harbor Marsh estuary. Although the slopes of predicted on observed concentrations were all equal to 1, in general, R^2's were low indicating substantial variability that could not be attributed to external inputs and mixing. This unexplained variability can be attributed to internal processes which cause concentrations to fluctuate around levels established by inputs. The net effects of internal processes on concentrations are thus of secondary importance to external inputs.

The relative influence of external inputs and internal processes on estuarine nutrient concentrations varies both across systems and temporally and spatially within systems. In the lower Hudson estuary, both DIN and DIP concentrations appear controlled by internal recycling processes while silicate may depend on external riverine input (Malone 1977). In the Providence River region of upper Narragansett Bay, nutrient concentrations are determined by riverine and sewage treatment plant discharges (Doering et al. 1990, Oviatt et al. 1984). In lower Narragansett Bay annual fluctuations in nutrient concentrations are largely driven by remineralization from the benthos (Pilson 1985a). In the Peel-Harvey estuary (Australia) the large external riverine input of phosphorus during the winter-spring is remineralized internally during the summer to fuel phytoplankton blooms (McComb and Humphries 1992).

One of the factors which influences the degree to which internal or external factors affect observed concentrations is hydraulic residence time (Officer 1980). In upper Narragansett Bay where external factors dominate, residence time is short, 1 to 8 days (mean=3.6 days, Asselin and Spaulding 1993). The average for Narragansett Bay as a whole including the lower Bay where internal processes dominate is 10 to 40 days (mean=26 days, Pilson 1985b). In Somes Sound (Maine), we calculated a short average residence time of 7 days (Doering and Roman 1994). The residence time for the Bass Harbor Marsh estuary is short, less than 3 days. This short replacement time of water ensures that concentrations in the system reflect those in the inputs.

Freshwater and Oceanic Inputs

Both freshwater brooks and the oceanic flood tide were significant sources of nutrients. Of the total of the two sources, 52% of the DIN came from freshwater and 48% from the ocean. For DIP, only 5% was delivered by freshwater brooks, while 95% entered from the ocean on the flood tide. The contribution of oceanic inputs to estuaries are rarely considered in nutrient budgets for such systems, but may be important (Nixon 1992). The oceanic flux of DIN into Narragansett Bay may equal all other sources of DIN combined (Nixon and Pilson 1984). Our results clearly demonstrate that the oceanic flux is both a significant source of nutrients, especially DIP, to the estuary and a key determinant of nutrient concentrations within the system.

Nitrogen to Phosphorus Ratios

The ratio of nitrogen to phosphorus in external inputs has been used to indicate which nutrient will most likely limit primary productivity in receiving waters (Hecky and Kilham 1988; Howarth 1988; Magnien et al. 1992). Both phytoplankton and the mat forming macroalgae require N and P in a molar ratio close to 16:1 (Redfield 1958, Gordon et al. 1981, Atkinson and Smith 1983).

Many estuaries exhibit seasonal and spatial shifts in nitrogen and phosphorus limitation (Fisher et al. 1992). On average, the Bass Harbor Marsh estuary shows a spatial shift in DIN/DIP ratios from high values at its head, indicating phosphorus limitation, to low values (<16:1) at its mouth indicative of nitrogen limitation. As Fig. 17 shows, this trend results both from a declining DIN concentration and an increasing DIP concentration towards the mouth of the estuary. The increase in DIP at the seaward end may be caused by 1) the geochemical release of DIP from suspended particulate matter with increasing salinity (Froelich 1988, Jordon et al. 1991) or enhanced release of DIP from saline sediments (Pomeroy et al. 1965). The latter process may be due to a lower phosphorus immobilization capacity of marine sediments at the high sulphate concentrations typical of ocean water (Caraco et al. 1990).

In our data both these internal processes would manifest themselves as an addition of DIP or a loss of organic or otherwise bound P. An addition of total P might also result from enhanced sediment release. While the observed concentration of DIP in the estuary tended to be higher than that predicted by the model from inputs alone, the difference was not statistically significant. Organic P exhibited no loss (slope of predicted on observed regression = 1.0, Table 13), while total P exhibited no gain (slope = 1.0).

Neither geochemical release from suspended material or enhanced benthic release of P appeared to cause addition of DIP. Rather increased DIP at the

seaward end of the Bass Harbor Marsh estuary results primarily from the oceanic input. The extensive intertidal mudflats in Bass Harbor, downstream of the marsh complex, may be a significant source of DIP.

The concentrations of all forms of nitrogen examined by the steady state box model could be explained by external inputs (Table 13). Ammonia tended to show removal but this was neither statistically significant nor reflected by a concomitant loss of organic N or total N, indicative of remineralization and subsequent uptake or an increase in nitrate + nitrite, an indication of nitrification (Berounsky and Nixon 1993). The decreasing concentration of DIN from head to mouth of the estuary is primarily a function of input from the brooks rather than internal processes.

The spatial shift in the N to P ratio observed in Bass Harbor Marsh is a consequence of differences in the relative N and P compositions of freshwater and oceanic inputs and their subsequent mixing in the estuary. The net effects of internal processes appear not to materially influence the proportionality of DIN and DIP. Thus, our results are more in line with those of Fisher et al. (1992) and Magnien et al. (1992). Both of these investigations stress the contribution of external inputs to spatial and temporal variation in N to P ratios and limiting nutrients in the Chesapeake Bay and several of its subestuaries.

Algal Mats and Nutrients

In this section we evaluate the potential importance of freshwater and oceanic nutrient sources to the growth of algal mats in the Bass Harbor Marsh estuary. While these external nutrient inputs largely establish observed nutrient concentrations in the estuary, the critical issue is whether these inputs contribute directly to the productivity of algal mats.

Our argument rests on the logic that if the water column pool is a source of nutrients for algal growth, and this pool is largely controlled by oceanic and freshwater inputs, then these inputs are important determinants of algal productivity in the estuary. The steady state box modeling effort has already demonstrated that concentrations in the estuary are largely a function of freshwater and oceanic inputs. It remains to be decided whether these nutrients contribute to algal growth. First, we present circumstantial evidence that nutrients are taken up from the water column. Secondly, we show a tendency for algal biomass to depend on nutrient input. Lastly, we link algal biomass, nutrient uptake and freshwater and oceanic input using results from the steady state box model.

The potential importance of the water column pool of nutrients can be inferred from a comparison of nutrient concentrations at Station 3 where the algal mat is present and at the adjacent Station 4 where there were no algae. The mean

salinities encountered at each station were similar as judged by a paired t-test (Table 14). Thus, water mass differences are unlikely to account for the lower nutrient concentration observed at Station 3 where algae were present (paired t-test, $p<0.05$, Table 14). The difference is more likely due to uptake of nutrients from the water column by the algae.

If nutrient inputs contribute directly to algal productivity, some relationship between nutrient input and algal productivity might be expected. We did not measure instantaneous macroalgal productivity. However, on longer time scales the magnitude of biomass present in the system reflects productivity. The weak statistical relationship between the input of DIN and monthly average biomass (Fig. 23) indicates that when nutrient inputs are high, algal biomass also tends to be high. At least on time scales of a month or so, nutrient inputs from both freshwater and the ocean appear to contribute directly to the productivity of the algal mats. Comparison of results from the steady state box model with temporal biomass trends provides a quantitative link between water column nutrient pool, inputs and algal productivity. The steady state box model predicts the concentration of the water column nutrient pool as a function of oceanic input, freshwater input and mixing. An observed concentration less than predicted implies removal of nutrients. This removal must occur at a rate higher than all inputs combined: those included in the model (freshwater and oceanic) and those not included in the model (benthic recycling). Thus, an observed concentration less than predicted implies that at least some of the oceanic and freshwater nutrient input has been removed. Conversely, an observed concentration greater than predicted implies a net addition to the system, over and above any losses.

Fig. 24 juxtaposes the net gain or loss of DIN in segment 3 of the model which spatially encompasses much of the algal mat, with fluctuations in algal nitrogen biomass. Algal mats exhibited two peaks in biomass during the growing season: one in June and one in July. These were separated by a precipitous decline in mid-June. After the July peak, biomass declined until late August. Algal nitrogen biomass then remained low and fairly constant before disappearing in November. Both peaks in algal biomass are associated with a removal of nutrients from the water column calculated from the model. This suggests not only that the water column pool is an important nutrient source but also that the nutrient input from freshwater and the ocean helps to fuel growth during periods of rapid biomass accumulation or net productivity. The declines of algal biomass in June and the late summer decline following the July peak are associated with an addition of nutrients calculated from the model . This gain of nutrients likely reflects regeneration of nitrogen from algal detritus. The apparent temporal lag between the late summer biomass decline and subsequent remineralization of detritus may be a sampling artifact in which peak nutrient addition to the water column was missed, or this may reflect slower regeneration owing to lower water temperature as fall approaches.

Table 14. Tidally and depth averaged salinity and concentration of DIN at stations 3 and 4. n=7 cruises in each case; (*) difference statistically significant by paired t-test ($p<0.05$). ns=not statistically significant ($p>0.05$).

Parameter	Station 3	Station 4	Difference
Mean Salinity $\pm$ SD	15.90 $\pm$ 10.75	18.94 $\pm$ 7.13	3.04 $\pm$ 4.03 (ns)
Mean DIN $\pm$ SD	1.51 $\pm$ 2.17	2.98 $\pm$ 2.85	1.47 $\pm$ 0.94 (*)

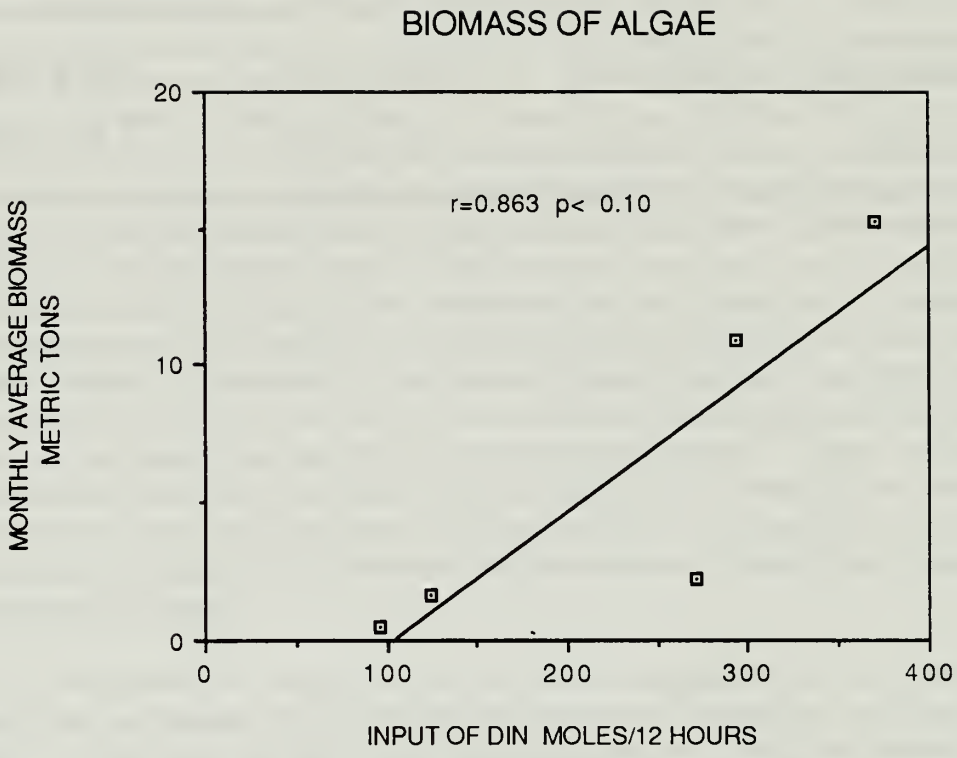


Fig. 23. Average monthly biomass of macroalgae in the marsh as a function of the flood tide input (oceanic and brooks) of dissolved inorganic nitrogen.

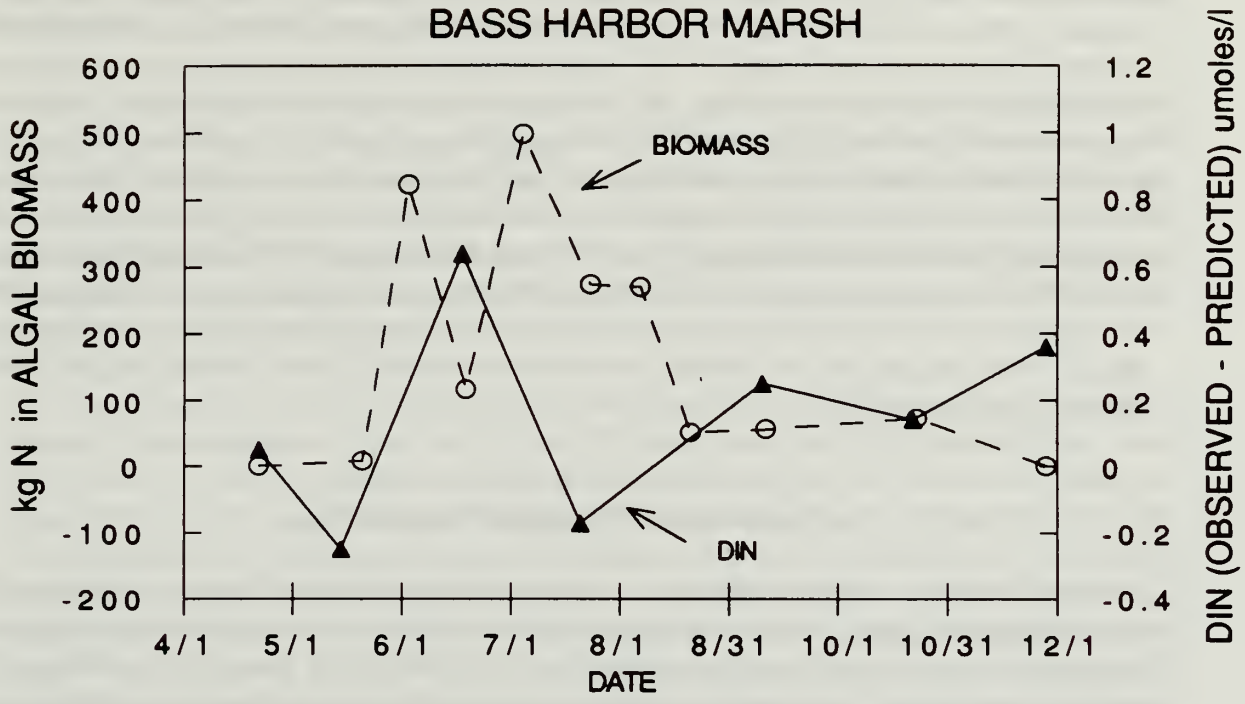


Fig. 24. Temporal fluctuations in macroalgal biomass and the difference between predicted and observed concentrations of dissolved inorganic nitrogen (DIN) calculated from box 3 of the steady state model. A difference greater than zero indicated nutrient addition to the water column, while a difference less than zero indicates nutrient removal from the water column.

Our results suggesting that *Enteromorpha*-dominated macroalgal mats in Bass Harbor Marsh depend on water column nutrients agree with other investigations. Mats of *Cladophora* and *Chaetomorpha* in Australia depend largely on water column nutrients (Birch et al. 1987, Lavery and McComb 1991). In very dense mats (>300 g/m^2), where oxygen becomes depleted (<2 $mg0_2/l$) nutrient release from sediments may be enhanced and this may become an important source (Lavery and McComb 1991). Biomass never achieved such high levels in Bass Harbor Marsh (see Fig. 5) and preliminary diel dissolved oxygen measurements in the algal mats did not suggest depletion to such low levels, at least for prolonged periods (see Fig. 6). Although sediment nutrient flux may contribute to algal mat production, we have no indication that the mats are enhancing this flux in the sense of Lavery and McComb (1991). Rather, our data show that 1) water column nutrients are taken up by algal mats, 2) the water column pool of nutrients is largely maintained by freshwater and oceanic input, and 3) these inputs are important determinants of algal mat growth in the Bass Harbor Marsh estuary.

Distribution of Aquatic Vegetation

Several factors no doubt contribute to the distribution of the three major species of submerged aquatic vegetation in the marsh. Salinity is probably important in limiting the occurrence of *Potamogeton* to the head of the estuary. *Ruppia maritima*, however, has a wide salinity tolerance and can grow in near fresh to full seawater (Day et al. 1989). While the distributions of macroalgae and *Ruppia* overlap, *Ruppia* is sparse or absent where macroalgae mats are prevalent. *Ruppia* has relatively high light requirements and seldom grows below a mean tidal level of 50 cm (Verhoeven 1980). Despite appropriate salinity, the relatively deep water (40-50 cm) in the basin around station 3 and shading by the floating macroalgae mat may effectively exclude *Ruppia* from the lower reaches of the estuary.

In general, vegetation changes from rooted aquatic angiosperms in the upper estuary to floating algal mats in the lower basin. Although other factors may contribute (see above), the distribution of DIN and DIP in the water column may also be an important determinant. Besides having very low DIP concentrations, the water column of the upper estuary has, on average, high DIN/DIP ratios, suggesting that DIP is in short supply relative to DIN. Rooted angiosperms may grow well here because they can access phosphorus in the sediments (McRoy et al. 1972).

Enteromorpha, the main component of the algal mats, lacks roots, and requires nitrogen and phosphorus in a ratio approximating the Redfield ratio of 16N:1P (Atkinson and Smith 1983). The algal mats occur in the lower basin of the estuary around station 3. On average, over the growing season, DIN and DIP concentrations at stations 3 and 4 are near the Redfield ratio (Fig. 17). Algal mats

are most prolific in the area of the estuary where, on average over the growing season, nutrients achieve a favorable ratio for growth. Green filamentous macroalgal species, such as *Cladophora*, are capable of luxury consumption of nutrients beyond those required for growth (Lavery and McComb, 1991). The concordance between the distribution of macroalgae and the seasonal average DIN/DIP ratio is thus not surprising.

While other factors, such as light availability, appropriate current velocities, or low wave action (McComb and Humphries 1992) certainly must also control the location of filamentous macroalgae in the estuary, the relative distribution of DIN and DIP appears important. While DIN enters the system at both ends, DIP is supplied mainly from the ocean. This difference in character of the two endmember inputs positions and maintains N:P ratios for appropriate algal mat growth in the lower estuary.

It is predicted by STELLA steady state modeling that if DIN input from Marshall Brook, the freshwater input with a landfill associated with the watershed, were decreased to loading levels equivalent to the non-impacted freshwater streams, the 16N:1P ratio would dramatically shift upstream toward station 6 (Fig. 18). We suggest that this portion of the estuary may not be conducive to prolific macroalgal growth for the following reasons; 1) DIN will be in limited supply, 2) existing *Ruppia* beds would serve to sequester a significant proportion of the available DIN, and 3) DIP will be in limited supply, but *Ruppia* can obtain P directly from sediment supplies. Our model runs point to the importance of the freshwater DIN in controlling the distribution of macroalgae in the estuary. Even if oceanic input of DIN to the marsh were increased by 50%, there would be little influence on the distribution and concentration of DIN in the estuary (Fig. 18). Although not predicted by the model, increases in oceanic input of DIP could serve to alter the N:P distributions in the system.

FISH FAUNA IN BASS HARBOR MARSH

INTRODUCTION

The objective of this portion of the ecological evaluation of Bass Harbor Marsh was to assess the species composition, distribution and biomass of the resident fish population. Our goal was to provide a baseline inventory of the fish species occurring within major habitat types of the marsh-estuarine ecosystem over a portion of the seasonal cycle (April-October). To accomplish this, beach seines were conducted on a periodic basis from October 1990 through August 1992, at 3 to 6 stations within the marsh. Ichthyoplankton tows were additionally taken over the same time period at a single station at the mouth of the estuary (station 1).

METHODS

Adult and juvenile finfish were collected with a 30 m by 1.2 m beach seine composed of 8 mm square stretch net, with a 1.2m by 1.2m by 1.2m fine mesh (5 mm) cod end. Collections were made at 3-6 stations on a periodic basis from October 1990 through August 1992 (Table 15). The stations (Fig. 25) were selected to range from high to low salinity and represent a suite of habitat types present in the estuary. At each station, the seine was hauled parallel to the long axis of the estuary for a distance of approximately 40 m before being pursed. With the exception of the initial collection (October 4, 1990) all fish in the seine bag were collected, preserved in formalin and returned to the laboratory for identification to species and enumeration. The initial collection (October 1990) was undertaken to provide a qualitative record of the species present in the estuary. For this collection, species were identified in the field with only a subsample of each species preserved and returned to the laboratory. The remainder of the original samples were released without enumeration.

Ichthyoplankton collections were made at station 1H from 3 October 1990 to 21 July 1992 (Table 16). Samples were taken using a 0.5 m plankton net with 505 µmoles/l mesh (standard for ichthyoplankton; Smith and Richardson 1977). Samples were fixed in about 6% formalin immediately following collection and returned to the laboratory. After at least one week and prior to identification, the samples were transferred to a 20% ethyl alcohol solution. Samples were progressively moved to 45% and 70% solutions of ethyl alcohol for storage as described in Jahn and Lavenberg (1986). Fish eggs and larvae were identified to the lowest taxonomic category possible and counted completely under a dissecting microscope.

Table 15. Station designations and sample dates for adult and juvenile finfish collections.

Stations	Sample Date
1H, 3, 6, 9	October 4, 1990
1H, 3, 6, 8.5, 9	May 5, 1991
1H, 3, 6, 8.5, 9	June 19, 1991
1H, A1, A2, 4.5, 6, 9	September 9, 1991
1H, 3, 6, 9	October 21, 1991
1H, 3, 6, 9	April 4, 1992
1H, 3, 6, 9	July 23, 1992
1H, A2, 3, 6, 9	August 20, 1992

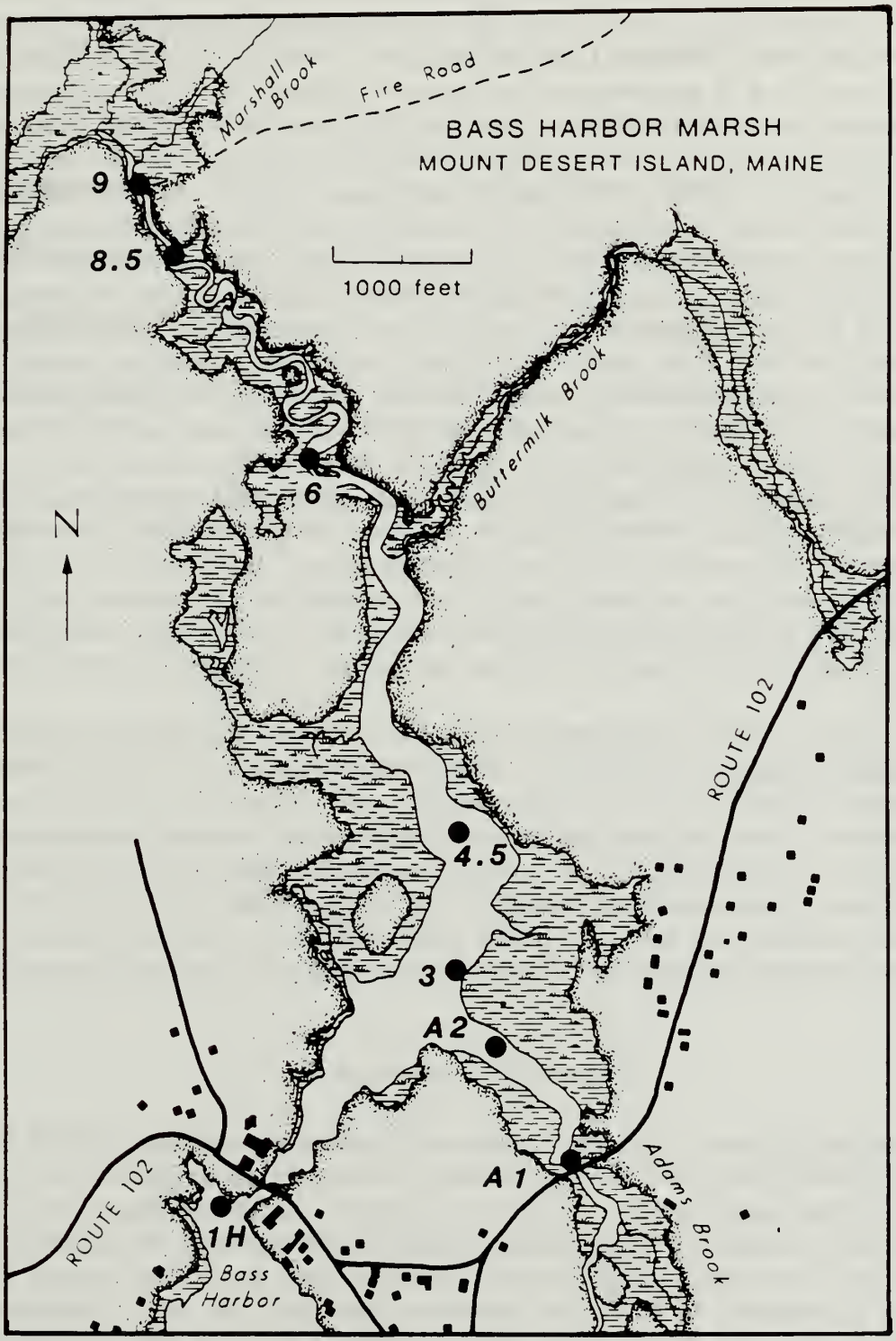


Fig. 25. Location of fish sampling stations.

Table 16. Sample dates for ichthyoplankton collected at Station 1H, Bass Harbor Marsh.

3 October 1990	8 July 1991
5 May 1991	23 July 1991
15 May 1991	10 September 1991
7 June 1991	22 October 1991
10 June 1991	22 April 1991
28 June 1991	21 July 1992
1 July 1991	

RESULTS

Adults and Juveniles

A total of 6,527 fishes representing 16 species (Table 17) was enumerated from the samples. Results (Table 17) indicate the most abundant fish species was the common mummichog, *Fundulus heteroclitus*, representing 44% of the total catch. The top 3 species comprised 82% of the total catch: common mummichog, fourspine sticklebacks (26%) (*Apeltes quadracus*) and Atlantic silverside (12%) (*Menidia menidia*). Finfish were most abundant at station 6, a marsh habitat characterized by the presence of *Ruppia*, a brackish water angiosperm (Fig. 26); total density was also high at station 1H, the most seaward sampling site characterized by a mud-sand bottom. Abundance was low at mid-marsh stations dominated by the presence of macroalgae, supporting Deegan et al.'s (1991) suggestion that dense algal mats may be correlated with low fish abundance. Species diversity was highest at the most seaward end of the estuary (station 1H) where 11 species were collected (Fig. 26). Increased richness at this station was due to the presence of juvenile herring (*Clupea harengus*), pollock (*Pollachius virens*), menhaden (*Brevoortia tyrannus*) and yellowtail flounder (*Pleuronectes ferrugineus*) within the harbor area. The most upstream station (station 9) also exhibited relatively high species diversity with the occurrence of 8 species (Fig. 26). Four species, the northern redbelly dace (*Phoxinus eos*), the golden shiner (*Notemigonus crysoleucas*), the bridle shiner (*Notropis bifrenatus*) and the brook trout (*Salvelinus fontinalis*) were present only at this freshwater station (Table 18).

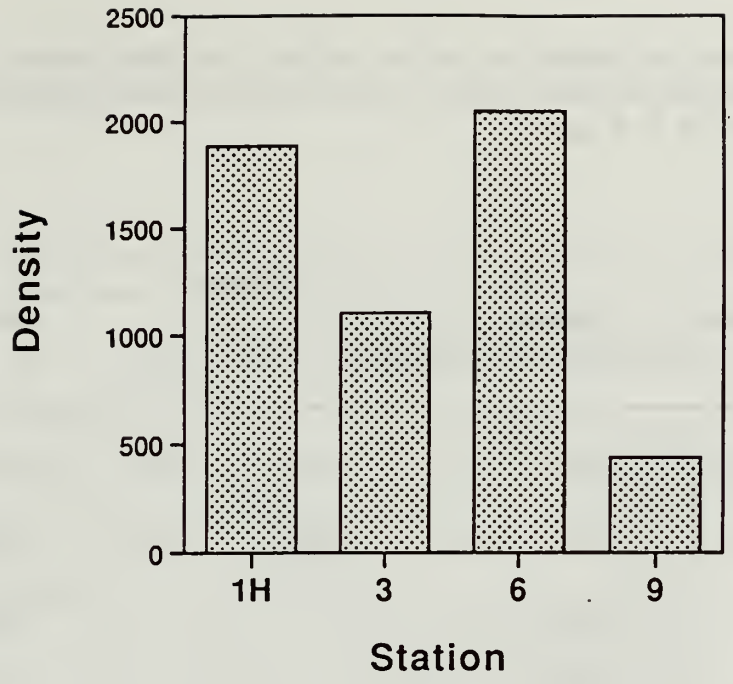
Additional differences occurred in the localized distribution of the Atlantic silverside within the marsh-estuary system (Table 18). Atlantic silversides were never collected at station 3. This species is highly abundant both upstream and downstream of these stations. Atlantic silversides are particularly susceptible to low oxygen concentrations and have been observed to actively avoid waters with low DO levels. Our data suggest that this area does become hypoxic (see Fig. 6b). Pulling the seine was extremely difficult at the macroalgae dominated stations and this may have allowed some fish (i.e., silversides) to avoid capture.

Seasonal Distribution

Total finfish abundance gradually increased from April through August with a peak value observed in September followed by a decline in abundance (Fig. 27). The two most abundant species (common mummichog and fourspine stickleback) were collected on all sampling dates (April through October, Fig. 28). Both species exhibited peak abundances during late summer (August and September). The mummichog gradually increased in abundance over the summer (Fig. 28) with the September peak composed of a large percentage of small fish representing the seasonal pulse of young-of-the-year. Peak abundance for the fourspine stickleback was seen in August following a similar gradual

Table 17. Total number of adult and juvenile fish seined from Bass Harbor Marsh, Acadia, Maine from October 1990 through August 1992.

Species (Common Name)	Abundance
Fundulus heteroclitus (common mummichog)	2,889
Apeltes quadracus (fourspine stickleback)	1,698
Menidia menidia (Atlantic silverside)	761
Clupea harengus (Atlantic herring)	322
Gasterosteus wheatlandi (twospine stickleback)	317
Pungitius pungitius (ninespine stickleback)	279
Gasterosteus aculeatus (threespine stickleback)	139
Pollachius virens (pollock)	61
Brevoortia tyrannus (Atlantic menhaden)	38
Notemigonus crysoleucas (golden shiner)	8
Anguilla rostrata (American eel)	4
Pleuronectes ferrugineus (yellowtail flounder)	3
Syngnathus fuscus (northern pipefish)	3
Salvelinus fontinalis (brook trout)	3
Phoxinus eos (northern redbellied dace)	2
Notropis bifrenatus (bridle shiner)	1



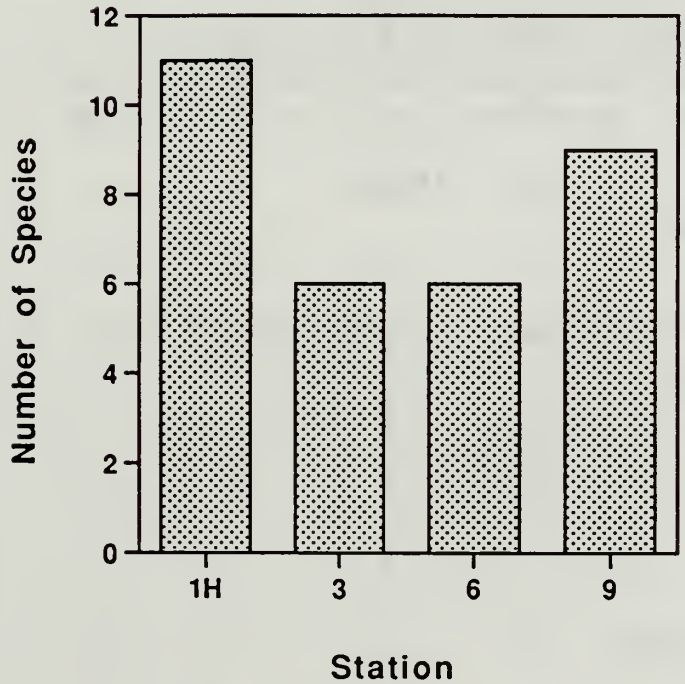


Fig. 26. Total density and number of species of adult and juvenile finfish at Bass Harbor Marsh sampling stations.

Table 18. Distribution of fishes by station within the Bass Harbor Marsh ecosystem. As noted in Table 15, most sampling effort was dedicated to stations 1H, 3, 6, and 9.

Species (Common Name)	Stations					
	Seaward				Landward	
	1H	A1/A2	3	4.5	6	9
Fundulus heteroclitus (common mummichog)	388	413	250	221	1,341	276
Apeltes quadracus (fourspine stickleback)	70	127	775	127	505	94
Menidia menidia (Atlantic silverside)	556	116	0	9	59	21
Clupea harengus (Atlantic herring)	322	0	0	0	0	0
Gasterosteus wheatlandi (twospine stickleback)	310	1	3	0	3	0
Pungitius pungitius (ninespine stickleback)	50	27	43	12	120	27
Gasterosteus aculeatus (threespine stickleback)	87	1	27	2	20	2
Pollachius virens (pollock)	61	0	0	0	0	0
Brevoortia tyrannus (Atlantic menhaden)	38	0	0	0	0	0
Notemigonus crysoleucas (golden shiner)	0	0	0	0	0	8
Anguilla rostrata (American eel)	0	0	4	0	0	0
Pleuronectes ferrugineus (yellowtail flounder)	3	0	0	0	0	0
Salvelinus fontinalis (brook trout)	0	0	0	0	0	3
Syngnathus fuscus (northern pipefish)	2	1	0	0	0	0
Phoxinus eos (northern redbellied dace)	0	0	0	0	0	2
Notropis bifrenatus (bridle shiner)	0	0	0	0	0	1

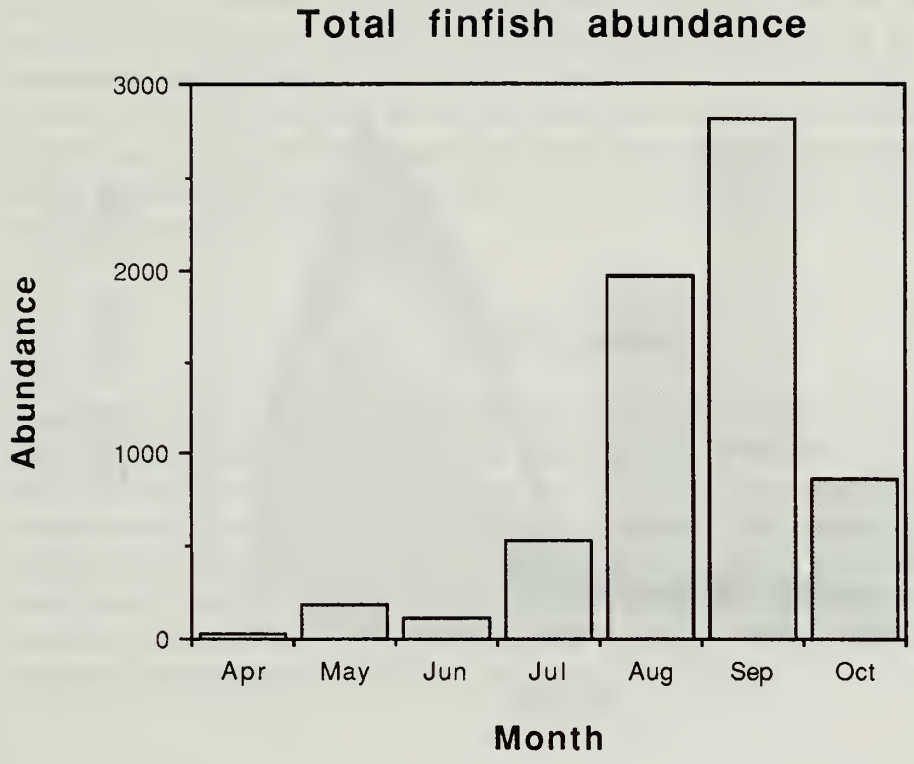


Fig. 27. Total finfish abundance by month in Bass Harbor Marsh.

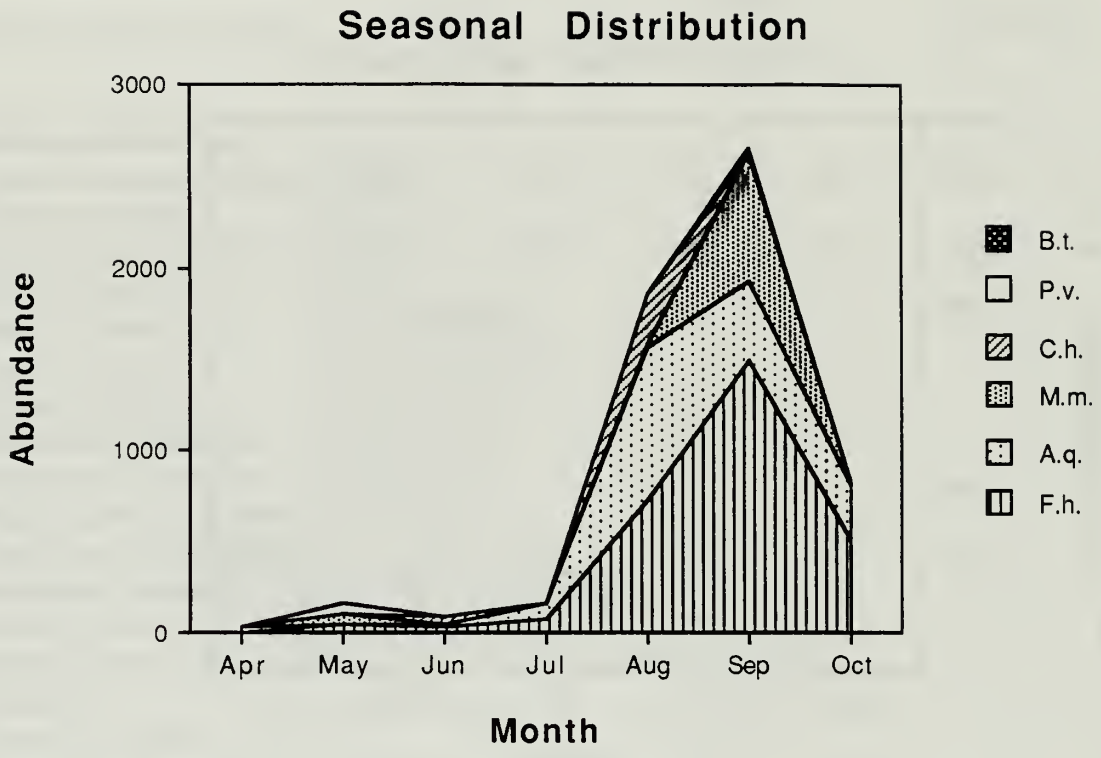


Fig. 28. Seasonal distribution of six species of finfish (adults and juveniles) in Bass Harbor Marsh.
B.t., Brevoortia tyrannus
P.v., Pollachius virens
C.h., Clupea harengus
M.m., Menidia menidia
A.q., Apeltes quadracus
F.h., Fundulus heteroclitus

increase throughout the spring and early summer (Fig. 28). Although present in May and again in August through October, Atlantic silverside were not collected in the estuary during June or July (Fig. 28).

Juvenile herring were relatively abundant during June and August (Fig. 28), while pollock and menhaden were present during a single month. Samples collected for all three species represent the seasonal presence of young-of-the-year. Pollock were present only during the spring while both herring and menhaden were most abundant during the late summer (Fig. 28). The threespine stickleback and ninespine stickleback were typically most abundant during the summer (July-September) while the twospine stickleback exhibited a major peak in July and was relatively rare throughout the rest of the sampling period (Fig. 29). The remaining species are relatively rare and seasonal distribution is poorly defined (Table 19).

Ichthyoplankton

Twelve species of fish were represented in the ichthyoplankton samples from the Bass Harbor Marsh system; five of these species were also collected as juveniles or adults while seven were present only in the plankton (Table 20). Herring larvae were the most abundant species collected with a total of 27 larvae from a single date (October 22, 1991) during the ebbing tide. Yellowtail eggs were the most abundant fish egg collected with a total of eight captured. The overall seasonal distribution (Fig. 30) indicates that eggs were most abundant in May and June while larvae were most abundant in October.

DISCUSSION

Life History Classification

The fish species collected in the Bass Harbor Marsh-Estuary system were assigned to life history groups (Table 21) based on Bigelow and Schroeder (1953) and Scott and Scott (1988). Following Ayvasian et al. (1992) species were classified into the following categories:

(1) Freshwater species - species normally confined to inland waters;
(2) Diadromous - anadromous or catadromous species;
(3) Residents - species that spawn in the estuary and spend all or a significant portion of their life there;
(4) Nursery species - species which use the estuary as a nursery ground, either spawning in the estuary or offshore. The adults most commonly move offshore in the winter;
(5) Marine - species found in adjacent marine waters and which visit the estuaries as adults.

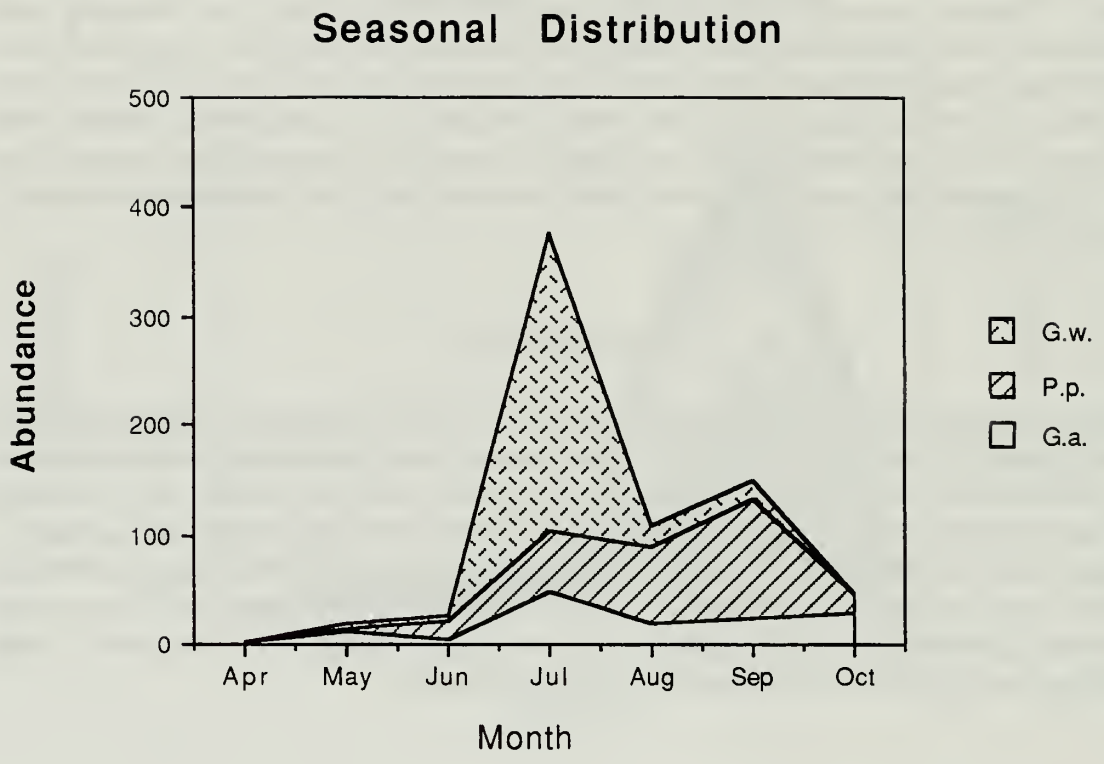


Fig. 29. Seasonal distribution of three species of finfish (adults and juveniles) in Bass Harbor Marsh.
G.w., Gasterosteus wheatlandi
P.p., Pungitius pungitius
G.a., Gasterosteus aculeatus

Table 19. Seasonal distribution of fishes within the Bass Harbor Marsh estuarine - marsh ecosystem.

Species (Common Name)	Oct 1990	April 1992	May 1991	June 1991	July 1992	Aug 1992	Sept 1991	Oct 1991
Fundulus heteroclitus (common mummichog)	3+	5	41	33	72	728	1497	510
Apeltes quadracus (fourspine stickleback)	5+	24	4	13	82	830	435	305
Menidia menidia (Atlantic silverside)	1+	0	58	0	0	15	684	4
Clupea harengus (Atlantic herring)	0	0	0	36	0	286	0	0
Gasterosteus wheatlandi (twospine stickleback)	1	0	4	5	273	18	16	0
Pungitius pungitius (ninespine stickleback)	4	0	4	18	57	70	110	16
Gasterosteus aculeatus (threespine stickleback)	1+	2	11	4	48	20	24	30
Pollachius virens (pollack)	0	0	61	0	0	0	0	0
Brevoortia tyrannus (Atlantic menhaden)	0	0	0	0	0	0	38	0
Notemigonus crysoleucas (golden shiner)	4	0	0	4	0	0	0	0
Anguilla rostrata (American eel)	0	1	0	1	2	0	0	0
Pleuronectes ferrugineus (yellowtail flounder)	0	0	0	0	0	0	3	0
Syngnathus fuscus (northern pipefish)	0	0	0	3	0	0	0	0
Salvelinus fontinalis (brook trout)	0	0	3	0	0	0	0	0
Phoxinus eos (northern redbellied dace)	1	0	0	1	0	0	0	0
Notropis bifrenatus (bridle shiner)	0	0	0	0	0	1	0	0

Table 20. Total number of eggs and larval fish collected from Bass Harbor Marsh, Acadia, Maine from October 1990 through July 1992.

Species (Common Name)	Eggs	Larvae
Menidia menidia (Atlantic silverside)	++	7
Clupea harengus (Atlantic herring)	0	27
Gasterosteus aculeatus (threespine stickleback)	0	2
Pleuronectes ferrugineus (yellowtail flounder)	8	1
Merluccius bilinearis (silver hake)	0	1
Melanogrammus aeglefinus (haddock)	4	0
Pollachius virens (pollock)	1	0
Urophycis tenuis (white hake)	7	1
Enchelyopus cimbrius (fourbeard rockling)	4	3
Mugil cephalus (striped mullet)	1	0
Ulvaria subbifurcata (radiated shanny)	0	2
Scomber scombrus (Atlantic mackerel)	0	1

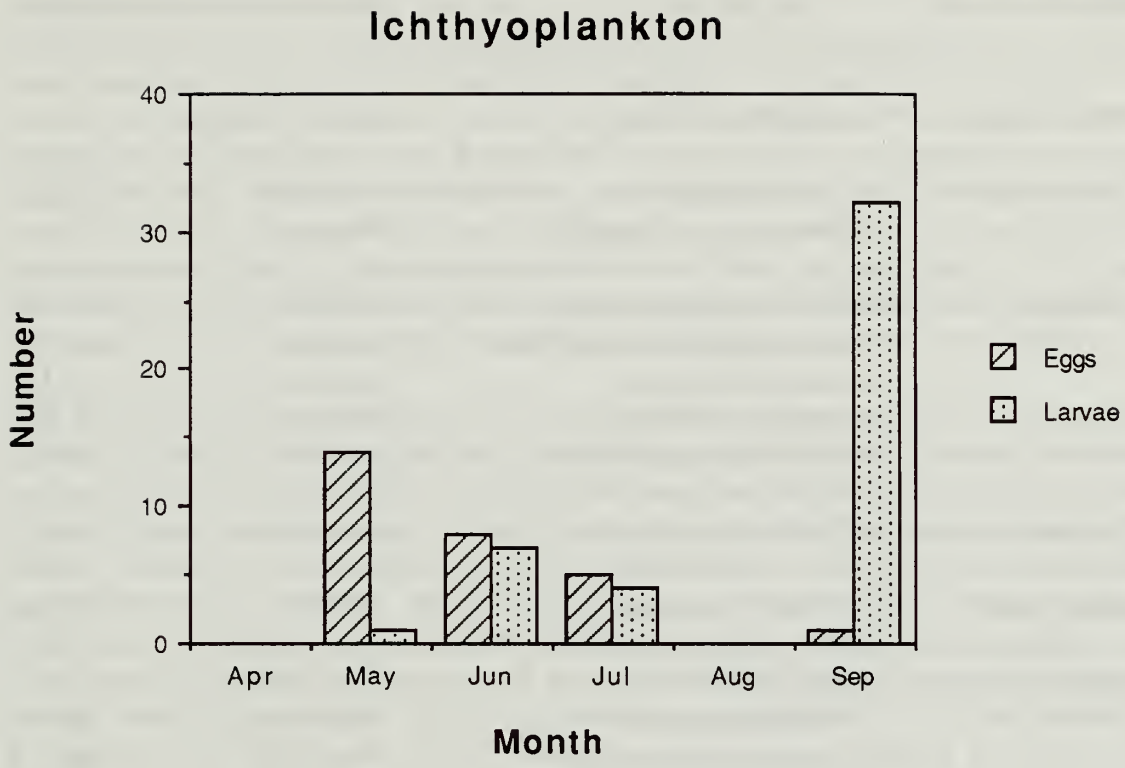


Fig. 30. Total ichthyoplankton abundance (eggs and larvae) by month in Bass Harbor Marsh.

Table 21. Life history categories and age classification for finfish collected in Bass Harbor Marsh. A=adult, J=juvenile, L=larvae, E=egg.

Family	Species	Life History Classification	Age Class
Anguillidae	*Anguilla rostrata*	Diadromous	J
Clupeidae	*Clupea harengus*	Nursery	L, J
	Brevoortia tyrannus	Nursery	J
Gadidae	*Merluccius bilinearis*	Marine	L
	Melanogrammus aeglefinus	Marine	E
	Pollachius virens	Marine	E, J
	Urophycis tenuis	Marine	E, L
	Enchelyopus cimbrius	Marine	E, L
Cyprinodontidae	*Fundulus heteroclitus*	Resident	J, A
Atherinidae	*Menidia menidia*	Nursery	E,L,J,A
Gasterosteidae	*Apeltes quadracus*	Resident	J, A
	Pungitius pungitius	Resident	J, A
	Gasterosteus aculeatus	Resident	L, J, A
	Gasterosteus wheatlandi	Resident	J, A
Syngnathidae	*Syngnathus fuscus*	Resident	J, A
Mugilidae	*Mugil cephalus*	Nursery	E
Stichaeidae	*Ulvaria subbifurcata*	Resident	L
Pleuronectidae	*Pleuronectes ferrugineus*	Marine	E, L, J
Scombridae	*Scomber scombrus*	Marine	L
Salmonidae	*Salvelinus fontinalis*	Freshwater	J
Cyprinidae	*Notemigonus crysoleucas*	Freshwater	J
	Notropis bifrenatus	Freshwater	A, J
	Phoxinus eos	Freshwater	A, J

A total of twenty-three species from eighteen families were found in the Bass Harbor Estuary when all life stages are included (eggs, larval fish, juveniles and adults). Seven species in four families were present only as ichthyoplankton in the estuary while sixteen species in twelve families were taken as juvenile or adult finfish. This compares with twenty-four species (adults and juveniles) in 15 families taken by Ayvasian et al. (1992) during a 21-month sample period in Wells, Maine and fourteen species in 8 families taken by McCleave and Fried (1975) during a two-month summer sampling near Wiscasset, Maine. A large number of sand lance were present in Wells, Maine making it the most abundant species collected. Sand lance were not collected in either the Bass Harbor Marsh system or by McCleave and Fried (1975). Ninespine sticklebacks, Atlantic menhaden and common mummichog were the next most abundant species found in Wells, Maine while mummichog, fourspine stickleback and Atlantic silverside were the top three species collected in Bass Harbor Marsh. The most abundant species present in the tidal cove sampled by McCleave and Fried (1975) were alewife/blueback herring, mummichog, Atlantic silverside and herring.

The average percent contribution of different life history groups to the overall density of fish for all sampling periods indicates that the overwhelming majority are residents (Fig. 31). Resident species comprised 81% of the catch in Bass Harbor Marsh compared to 25% of the catch in Wells, Maine (Ayvasian et al. 1992). Nursery species were second in importance with 17% of the density compared to 16% in Wells. The resident species were dominated by large catches of both mummichog and fourspine stickleback while the nursery species were dominated by Atlantic silverside and Atlantic herring. The additional life history groups contributed little (~2%) to the total composition (Fig. 31). As noted by Ayvasian et al. (1992) the abundance of residents outweighed the other life history groups because of both their seasonal persistence throughout the sampling period and breeding within the estuary.

Species composition was also examined relative to life history group (Fig. 31). The majority of species collected were resident species (38% based on 16 species) as was also noted by Ayvasian et al. (1992) in Wells, Maine (42% based on 24 species). In the Bass Harbor Marsh system the number of freshwater species (25%) was closely followed by both nursery species (19%) and marine species (12%).

Life History

The life histories for the five most abundant species (common mummichog, fourspine stickleback, Atlantic silverside, Atlantic herring and twospine stickleback) are described below based on information from Bigelow and Schroeder (1953). Three of the five species (mummichog, fourspine and twospine sticklebacks) are classified as estuarine residents and were generally taken

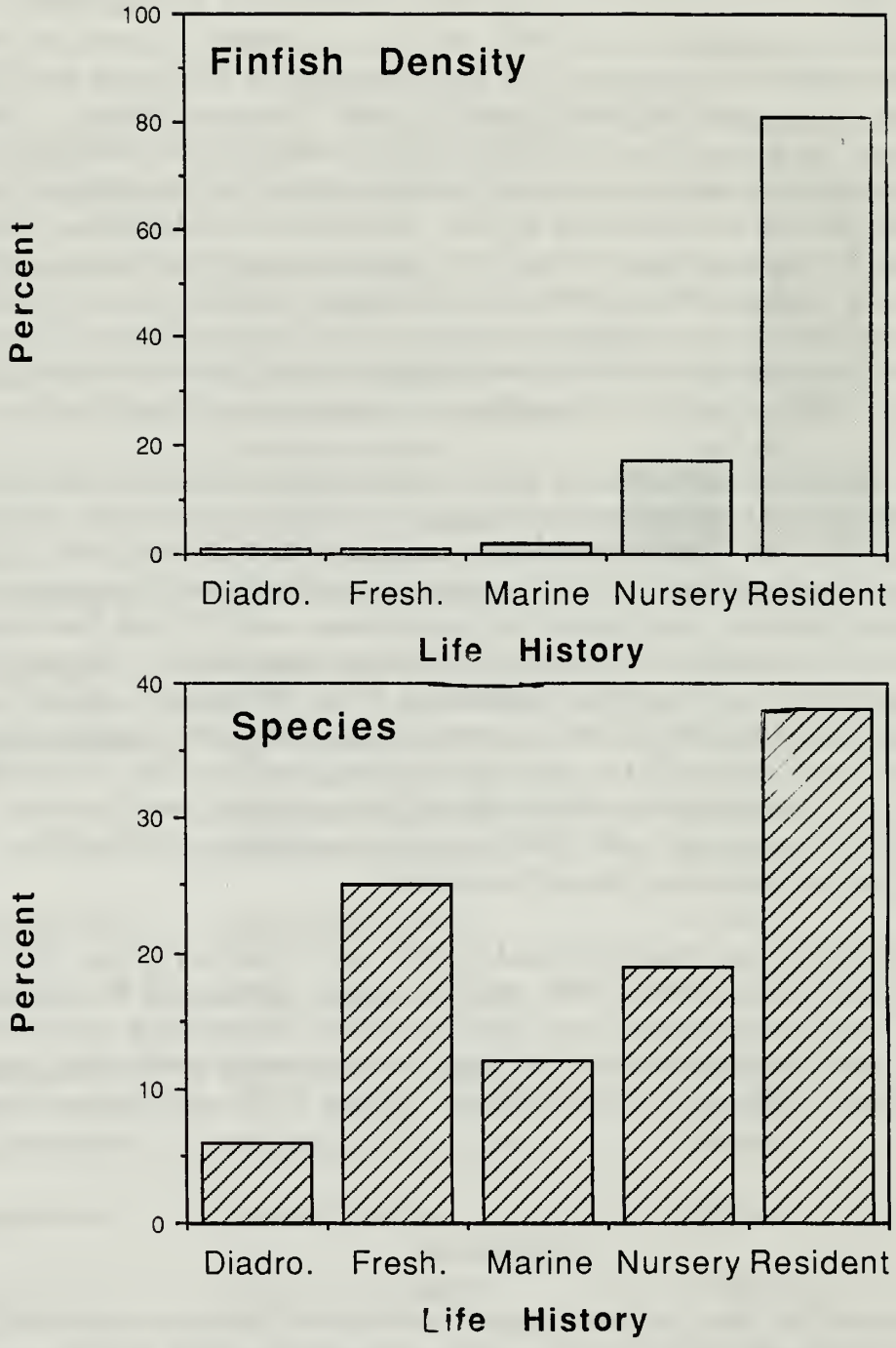


Fig. 31. Percent total density and percent species composition according to life history for adult and juvenile finfish in Bass Harbor Marsh.

throughout the sampling cycle with the exception that twospine sticklebacks were not collected in April. The Atlantic silverside is a nursery species which spawns in the estuary. The Atlantic herring, the only important commercial species collected in high abundance, is also classified as a nursery species. Both Atlantic silverside eggs and larval herring were collected in the estuary.

Common mummichog - The common mummichog is typically found in tidal creeks and shallow estuarine waters. Mummichogs are resistent to a lack of oxygen and occur from brackish to freshwater. In the Bass Harbor Marsh they occurred from seawater to the freshwater station (Station 9) with peak occurrence in the upper estuary. Mummichogs overwinter in a sluggish state on the bottom of deeper holes and creeks and remain within the estuary throughout their life cycle. Mummichogs are omnivorous feeders who spawn during summer (June-early August). The eggs are demersal and hatch in 9 to 18 days. The fish is characterized as 'universal' in suitable shallow-water locations around the entire coastline of Maine. The mummichog is of some commercial value as a bait fish.

Fourspine stickleback - The fourspine stickleback frequently inhabits salt marshes where it is often found with other sticklebacks and mummichogs. In the Bass Harbor Marsh it was most abundant in the mid-regions of the estuary at stations 3 and 6. It is primarily a salt water and brackish water species which may enter freshwater. In general, it is restricted to shallow waters, near the coast and is rarely found far out in the open ocean. This stickleback is common all along the shores of Maine (its northern limit) and unlike the threespine stickleback it is more closely restricted to estuaries. The fourspine stickleback is a year-round resident which breeds from May through July. The eggs are demersal and guarded in a nest by the male during a six-day incubation period. Newly hatched larvae are about 4.5 mm long and densely pigmented.

Atlantic silverside - Atlantic silverside is an important forage species which occupies bays, river mouths, sandy shores, tidal creeks and estuaries, always close to shore. They frequent brackish as well as sea water and are rarely found in deep water. It is one of the most abundant estuarine species throughout its range. Ayvasian et al. (1992) noted that Atlantic silverside were found in sandy and marsh stations in Wells, Maine, while they were restricted to sandy and open bottom stations in Waquoit Bay, Massachusetts. They felt that the shift in habitat in Waquoit Bay was a response to the presence of tidewater silversides, a species present in Massachusetts but not found in Maine. Atlantic silverside spawn from May through early July with eggs deposited on sandy bottoms among sedge grass above the low-water mark. The eggs each bear a bunch of sticky filaments which adhere to vegetation and hatch in 8 or 9 days. The species is considered a nursery species since it exits the estuary during the winter. In Bass Harbor Marsh, the species exhibited a bimodal seasonal distribution being present during the spring and late summer but absent in June and July.

Twospine stickleback - Twospine sticklebacks occur in both salt and brackish water along the coast of Maine. Like other sticklebacks this is distinctively a shore fish which lives in estuarine waters throughout its life, occurring from seawater to freshwater. In Bass Harbor Marsh, twospine sticklebacks were primarily collected at the seaward end of the estuary (station 1H) and rarely at less saline stations. Bigelow and Schroeder (1953) note that like its relative, the threespine stickleback, it is a year-round resident along shore, entering creeks and marsh streams in the spring to spawn and moving into somewhat deeper water for the summer. Like other sticklebacks, this species is a nest builder with the males guarding the eggs until they hatch. Spawning most likely occurs from May to June in Maine. Within the Bass Harbor Marsh system peak abundance occurred in June and July, perhaps suggesting a somewhat delayed spawning season relative to more southerly areas.

Atlantic herring - The herring is an open water fish which travels in schools throughout the Gulf of Maine. Spawning occurs along shore from July through August with the demersal eggs deposited primarily on rocky, gravelly or pebbly bottoms but never on soft mud. After hatching larvae may move inshore to estuarine nursery grounds. In the northeastern part of the Gulf herring are more plentiful in their inshore center of abundance than on offshore banks. In Bass Harbor Marsh, both juvenile and larval herring were collected in relatively high abundance. The size of the juvenile fish collected in the marsh suggests that they are the young-of-the-year. Typically these individuals thin out from the shore waters after the middle of October. Large mature herring are encountered along shore only during and after the spawning season. Herring have previously been reported as spawning commonly, though irregularly at Mount Desert Island.

Ichthyoplankton

The small size of the net and the short sampling period (10 minutes) resulted in very low counts for both eggs and larvae. The data do however provide a qualitative assessment of the status of the marsh as a spawning and/or nursery area for finfish. Chenoweth (1973) noted 22 species of fish collected during a two-year ichthyoplankton sampling program along the central Maine coast region (January to August 1968 and November to October 1970). Our species list was somewhat lower with only 12 species recorded (six of which were present in the central Maine samples). Differences in sampling techniques as well as geographic areas and sample season may be responsible for the variation observed between sites. Chenoweth (1973) used a depressor trawl with a 2 mm mesh opening that was towed for 30 minutes at 4 knots. Such gear most likely collects larger and older larvae and may be biased towards demersal species.

Our data indicate that Bass Harbor Marsh is an important nursery area for Atlantic herring, a species of commercial value. This is a pelagic species which produces demersal eggs and uses the estuary as a nursery area during its larval

stage (October to May, Chenoweth 1973). Other commercially important species were collected in the plankton in relatively low numbers and it is difficult to determine how important the marsh is as nursery habitat for these species.

CONCLUSIONS

The fish fauna collected in the Bass Harbor Marsh system indicate that the marsh is an important nursery habitat for young-of-the-year and juvenile fishes (some with commercial value). The faunal composition and dominance pattern agree with other published reports on dominant taxa in Maine estuaries and tidal coves (Targett and McCleave 1974; McCleave and Fried 1975; Ayvasian et al. 1992). The species diversity is somewhat lower than that found at Wells, Maine (Ayvasian et al. 1992) but in close agreement with that noted by McCleave and Fried (1975). The assemblage is characteristic of a boreal fauna with a high percentage of estuarine residents (Whitlach 1982). Regarding brook trout (*Salvelinus fontinalis*), only three individuals were collected during our sampling program. Use of a seine to collect brook trout is not an ideal method. Perhaps an electroshocking technique would have been more successful. However, our collection of brook trout at the freshwater station does indicate that Bass Harbor Marsh provides habitat for this species.

BENTHIC MACROFAUNA IN BASS HARBOR MARSH

INTRODUCTION

Benthic macrofauna (infauna) play a key role in marine, estuarine and freshwater ecosystems. Benthic animals are involved in processes that include sedimentation of water column particles, removal of planktonic organisms through feeding, reworking of the bottom sediment, nutrient regeneration, and bioaccumulation of toxic chemicals. Perhaps most importantly, benthic macrofauna are a critical link in the transfer of food and energy from phytoplankton and aquatic vegetation to higher trophic levels. Polychaetes, amphipods, and clams are eaten by finfish, crabs, shrimp, and lobsters, as well as shorebirds and water fowl (e.g. Virnstein 1977, Quammen 1984, Roman et al. 1989). In addition, because benthic organisms are important prey of so many animals, they can transfer toxic substances up the food chain (Bilyard 1987).

The analysis of benthic community composition can be a valuable addition to measurements of water column parameters and other biotic resources in determining the impact of nutrient inputs over time. The benthic community is long-lived and spatially stable compared to water column organisms (Bilyard 1987, Germano and Rhoads 1989, National Research Council 1990a, 1990b). Thus the sediments and animals living within are a better integrator of long-term enrichment than is the water column (Pearson and Rosenberg 1978, Germano and Rhoads 1989).

The changes in benthic macrofaunal communities that occur in response to pollution and enrichment are well-documented (National Research Council 1990b, review by Pearson and Rosenberg 1978) and monitoring of benthic organisms is commonly done to assess environmental quality around wastewater treatment facility outfalls. The benthic response to eutrophication and organic enrichment is often an increase in macrofaunal abundance and biomass, with shifts in species composition (Pearson and Rosenberg 1978, Cederwall and Elmgren 1980). Benthic animals are extremely sensitive to habitat disturbance, including organic enrichment of sediments (Bilyard 1987), but tolerance varies greatly between species. Opportunistic species that are less numerically abundant under normal conditions in estuaries can become dominant members of the benthic community (Beatty 1991).

As part of the study to determine if nutrient enrichment is occurring in the Bass Harbor Marsh estuary and if so, if it is an important factor in some of the habitat and faunal changes observed there over the years, benthic macrofauna were sampled on a periodic basis from October 1990 through August 1992, at four stations within the marsh and one station just outside in adjoining Bass Harbor. Stations were selected to range from high to low salinity and represent the major habitat types of the marsh-estuarine system. The objective of this part of the

ecological evaluation of Bass Harbor Marsh was to provide a baseline inventory of the species composition and distribution of benthic macrofauna within the estuary. This information will provide a benchmark of current conditions against which future changes can be compared.

METHODS

Benthic macrofauna were sampled at five stations (Fig. 32): 1H, 2, 3, 6, and 9. The most seaward site was station 1H, which was characterized by a mud-sand bottom. It was selected to identify the organisms potentially seeding the estuary from Bass Harbor. Station 2 was chosen to represent the lower estuary and was predominantly marine. The upper three sites were each characterized by different submerged aquatic vegetation. Station 3 was an area dominated by floating or attached marine macroalgae (*Enteromprpha* and others), station 6 was dominated by the brackish-water angiosperm *Ruppia maritima*, and station 9, the freshwater end, was dominated by the freshwater angiosperm *Potamogeton*.

Preliminary sampling was done in October 1990 at three stations (2, 3, and 9), 2 replicate cores each, to test small core sampling gear in the field. Sampling occurred on four occasions in 1991 and three in 1992 (Table 22). The August 1991 trip was cancelled because of Hurricane Bob but between 1990 and 1992, all months from May to October were sampled at least once. Two sizes of cores, 3 replicates each, were taken haphazardly from each of the five sites. Smaller cores were taken to determine species composition of benthic macrofauna of surface sediments. Larger cores were taken to get estimates of larger animals (epifauna and infauna), as well as deeper-dwelling animals, neither of which would be sampled effectively by the smaller cores.

Sampling was done from a canoe at low tide. First, smaller cores were taken with a remote corer that consisted of a 2" diameter stainless steel core tube attached to a ring on a rope (Table 22). The top 2 cm of each core was sliced off and placed in a 9 oz glass jar, preserved with formalin (final concentration: 10%), and buffered with $CaCO_3$. Next, larger cores were taken. We had a serious limitation on the size of the corer because the operation took place from a canoe. We used a 6.5" diameter Plexiglass corer that sampled approximately 20 cm in depth (Table 22). The sediment sampled was released into a bucket and then poured onto a 58 cm x 36 cm screen with 3 mm openings. The screen was gently shaken through the water, taking care not to let water over the sides, to rinse the mud through and leave the animals behind on the screen. Animals were picked off with tweezers, placed in a jar, and preserved and buffered (as above).

All cores were stained with rose bengal in the laboratory at the University of Rhode Island. For analysis of small cores, samples were washed through a 0.3 mm sieve. Animals retained on the sieve were identified to the lowest taxonomic category possible and enumerated under a stereomicroscope. Oligochaetes and

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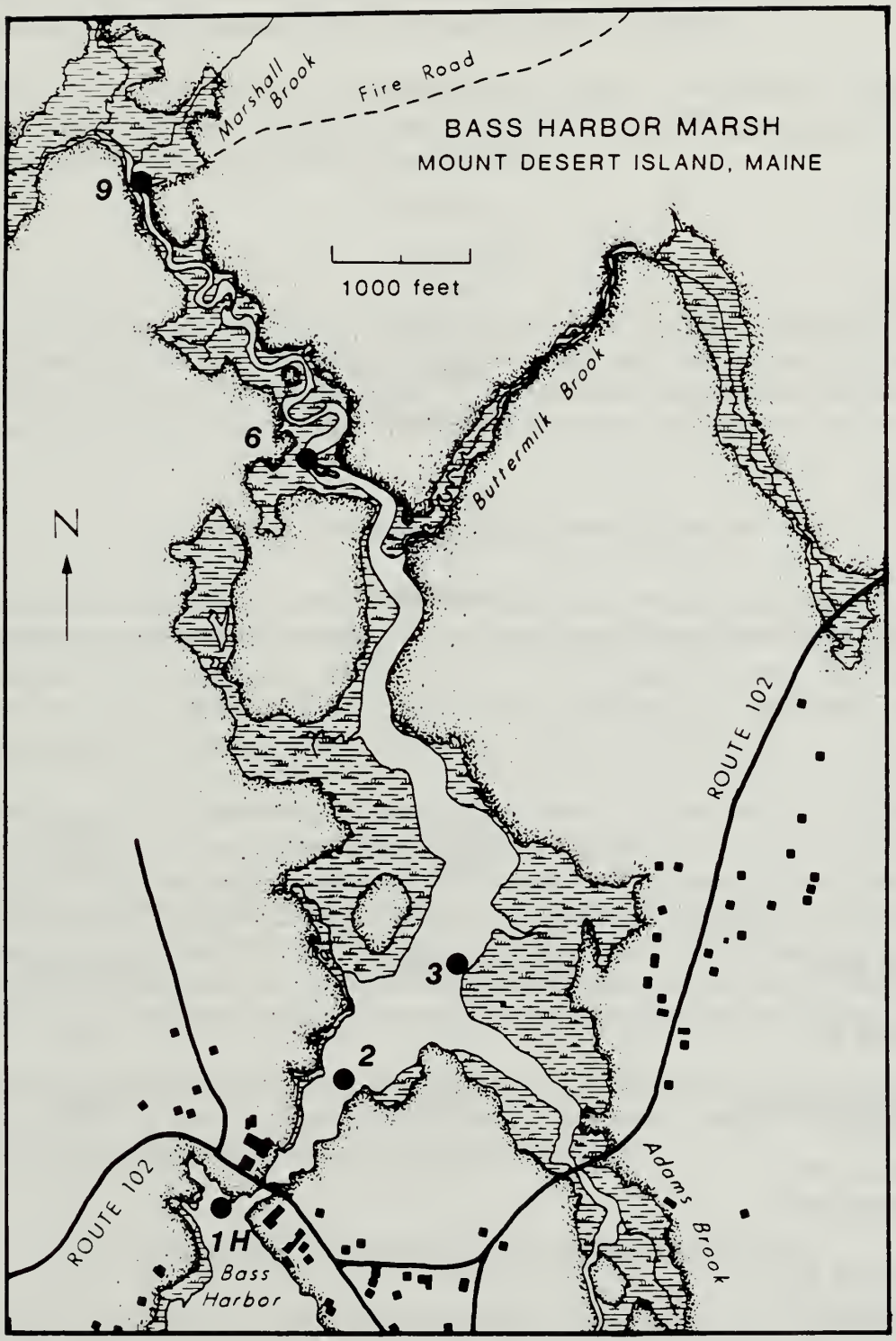


Fig. 32. Benthic macrofauna sample stations.

Table 22. Benthic macrofaunal sampling dates for small cores. Large cores taken in 1991 only. Description of cores below.

Year	Date
1990	October 4
1991	May 16
	June 19
	September 10-11
	October 22-23
1992	May 12
	July 23
	August 20

	Small cores	Large cores
type of corer	stainless steel	plexiglass
diameter (in.)	2	6.5
surface area (cm^2)	20.3	214.1
depth of core analyzed (cm)	0 - 2	0 - 20
screen size for analysis (mm)	0.3	3

turbellarians were treated as taxonomic units because of the difficulty associated with identifying these organisms to a lower taxonomic level. Organisms often classified as meiofauna and too small to be quantitatively sampled by our methodology (e.g. nematodes, ostracods, and copepods) were not counted although notes were made if they were particularly abundant.

Please note two recent name changes: *Polydora ligni* is now *Polydora cornuta* and the genus *Scoloplos* is now *Leitoscoloplos* (S. Pratt, Univ. of RI, pers. comm.). The former names were used in the text and tables.

RESULTS

The species composition of the benthic community changed dramatically from Bass Harbor and the lower marsh, higher saline stations to the brackish and freshwater sites of the upper estuary. In addition, significant differences in animal abundances and number of species were observed between stations.

Animal Abundances and Species Richness

Total animal abundances were lowest for station 6, averaging around 20,000 m^{-2} over the two-year study period, while animals were four times more numerous at station 1H, averaging about 80,000 m^{-2} (Tables 23 and 26, Fig. 33). Abundances for the other three stations were intermediate, averaging between approximately 40,000 to 50,000 m^{-2} (Tables 24, 25, and 27; Fig. 33).

A total of 31 taxa (combining Chironomidae larvae and pupae as one taxonomic group) of macroinvertebrates were collected (Tables 23-27). The actual number of species might be higher since turbellarians and oligochaetes probably included several species; two genera of polychaetes (*Nereis* and *Scoloplos*) were not keyed to species for all samples (their small size made species identification difficult) and may include multiple species; insect larvae were only keyed to family level; and a few of the rarer animals have not yet been identified below class or order.

The average number of species increased from the freshwater and brackish end of the estuary to the seawater end (Fig. 34). There was a decline in species from station 2 to the site just outside the marsh (station 1H).

Distribution Of Faunal Groups Within The Estuary

A gradient in benthic community composition existed along the estuary (Fig. 35, Table 28). Polychaetes were abundant at the more saline sites and oligochaetes were most numerous just outside the marsh; mollusks were important at the two

Table 23. Station 1H, Bass Harbor Marsh, small core data.

		4Oct'90	4Oct'90	16May'91	16May'91	16May'91	19June'91	19June'91	19June'91	10Sept'91	10Sept'91	10Sept'91	22Oct'91	22Oct'91	22Oct'91
	Species	no cores		core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3
TURBELLARIA	Turbellarians			2	12	2	7	21	1	8	6	2	5	4	
OLIGOCHAETA	Oligochaetes			240	211	202	81	123	62	27	38	13	4	23	12
POLYCHAETA	*Capitella capitata*				1	2		1		6	5	2	5	13	1
	Fabricia sabella														
	Mediomastus ambiseta						1								
	Nereis sp.			4		4			2						
	Pholoe minuta														
	Polycirrus eximius														
	Polydora ligni			3	1			3	3	5	3	1		1	
	Pygospio elegans					1									
	Scoloplos sp.				4	2		2	2	6	9	6			
	Streblospio benedicti			9	10	10	1	14	6	20	27	15	6	28	29
	Tharyx acutus			12	2		1	2	1	11	2	6	1		1
	Unknown Polychaetes							2					8		
BIVALVIA	*Gemma gemma*										1				
	Mya arenaria														
	Tellina agilis														
	Unknown Bivalves														
GASTROPODA	*Hydrobia minuta*								1	1	1	1			
	Unknown Gastropods														
AMPHIPODA	*Corophium volutator*					1		2							
	Gammarus mucronatus														
	Gammarus tigrinus														
	Gammarus sp.			1											
	Unknown Amphipods														
MYSIDACEA	*Neomysis americana*														
DECAPODA	*Crangon septemspinosa*														
INSECTA	Chironomidae larvae								1		1				
	Chironomidae pupae														
	Heleidae larvae														
	Unknown Insects														
OTHER	Unknown Organisms				3								1		
	Total Turbellaria			2	12	2	7	21	1	8	6	2	5	4	0
	Total Oligochaeta			240	211	202	81	123	62	27	38	13	4	23	12
	Total Polychaeta			28	18	19	3	24	14	48	46	30	20	42	31
	Total Bivalvia			0	0	0	0	0	0	0	1	0	0	0	0
	Total Gastropoda			0	0	0	0	0	1	1	1	1	0	0	0
	Total Amphipoda			1	0	1	0	2	0	0	0	0	0	0	0
	Total Mysidacea			0	0	0	0	0	0	0	0	0	0	0	0
	Total Decapoda			0	0	0	0	0	0	0	0	0	0	0	0
	Total Insecta			0	0	0	0	0	1	0	1	0	0	0	0
	Total Other Orgs.			0	3	0	0	0	0	0	0	0	1	0	0
	Total Organisms			271	244	224	91	170	79	84	93	46	30	69	43
	Number of species			7	8	8	5	9	9	8	10	8	7	5	4
	Total per m2			133706	120385	110517	44898	83875	38977	41444	45884	22695	14801	34043	21215
	Ave. of 3 cores/m2			121536			55916			36675			23353		

Table 23. (continued).

Species	12May'92 core 1	12May'92 core 2	12May'92 core 3	23July'92 core 1	23July'92 core 2	23July'92 core 3	20Aug'92 core 1	20Aug'92 core 2	20Aug'92 core 3
Turbellarians	23	17	9	10	3	2	9	2	4
Oligochaetes	230	626	348	55	58	39	140	65	53
Capitella capitata	2	1	1	6	1		15	3	3
Fabricia sabella									
Mediomastus ambiseta									
Nereis sp.				1			1		
Pholoe minuta									
Polycirrus eximius									
Polydora ligni	1	2		3	1		4		1
Pygospio elegans		9							
Scoloplos sp.	2	3	2			1	3	2	
Streblospio benedicti	31	20	18	11	9	3	22	21	19
Tharyx acutus	4	1	7	8	1	3	6	1	3
Unknown Polychaetes	6	52	1		2	2			
Gemma gemma									
Mya arenaria									
Tellina agilis									
Unknown Bivalves									
Hydrobia minuta		3					1		
Unknown Gastropods	1								
Corophium volutator									
Gammarus mucronatus									
Gammarus tigrinus									
Gammarus sp.									
Unknown Amphipods									
Neomysis americana									
Crangon septemspinosa			1						
Chironomidae larvae									
Chironomidae pupae									
Heleidae larvae									
Unknown Insects							1		
Unknown Organisms	2	4		1					
Total Turbellaria	23	17	9	10	3	2	9	2	4
Total Oligochaeta	230	626	348	55	58	39	140	65	53
Total Polychaeta	46	88	29	29	14	9	51	27	26
Total Bivalvia	0	0	0	0	0	0	0	0	0
Total Gastropoda	1	3	0	0	0	0	1	0	0
Total Amphipoda	0	0	0	0	0	0	0	0	0
Total Mysidacea	0	0	0	0	0	0	0	0	0
Total Decapoda	0	0	1	0	0	0	0	0	0
Total Insecta	0	0	0	0	0	0	1	0	0
Total Other Orgs.	2	4	0	1	0	0	0	0	0
Total Organisms	302	738	387	95	75	50	202	94	83
Number of species	10	11	8	8	7	6	10	6	6
Total per m2	149001	364114	190938	46871	37004	24669	99663	46378	40951
Ave. of 3 cores/m2	234684			36181			62330		
± standard error	±65837			±6422			±18732		

Species	Summary Information Ave./21 cores	Ave. per m2	% of total
Turbellarians	7.1	3501	4.3
Oligochaetes	126.2	62260	76.4
Capitella capitata	3.2	1598	2.0
Fabricia sabella	0.0	0	0.0
Mediomastus ambiseta	0.0	23	0.0
Nereis sp.	0.6	282	0.3
Pholoe minuta	0.0	0	0.0
Polycirrus eximius	0.0	0	0.0
Polydora ligni	1.5	752	0.9
Pygospio elegans	0.5	235	0.3
Scoloplos sp.	2.1	1034	1.3
Streblospio benedicti	15.7	7730	9.5
Tharyx acutus	3.5	1715	2.1
Unknown Polychaetes	3.5	1715	2.1
Gemma gemma	0.0	23	0.0
Mya arenaria	0.0	0	0.0
Tellina agilis	0.0	0	0.0
Unknown Bivalves	0.0	0	0.0
Hydrobia minuta	0.4	188	0.2
Unknown Gastropods	0.0	23	0.0
Corophium volutator	0.1	70	0.1
Gammarus mucronatus	0.0	0	0.0
Gammarus tigrinus	0.0	0	0.0
Gammarus sp.	0.0	23	0.0
Unknown Amphipods	0.0	0	0.0
Neomysis americana	0.0	0	0.0
Crangon septemspinosa	0.0	23	0.0
Chironomidae larvae	0.1	47	0.1
Chironomidae pupae	0.0	0	0.0
Heleidae larvae	0.0	0	0.0
Unknown Insects	0.0	23	0.0
Unknown Organisms	0.5	258	0.3
	165.2	81525	100.0
Total Turbellaria	7.1	3501	4.3
Total Oligochaeta	126.2	62260	76.4
Total Polychaeta	30.6	15083	18.5
Total Bivalvia	0.0	23	0.0
Total Gastropoda	0.4	211	0.3
Total Amphipoda	0.2	94	0.1
Total Mysidacea	0.0	0	0.0
Total Decapoda	0.0	23	0.0
Total Insecta	0.1	70	0.1
Total Other Orgs.	0.5	258	0.3
Total Organisms	165.2	81525	100.0
Number of species	7.6		

Table 24. Station 2, Bass Harbor Marsh, small core data.

		4Oct'90	4Oct'90	16May'91	16May'91	16May'91	19June'91	19June'91	19June'91	10Sept'91	10Sept'91	10Sept'91	22Oct'91	22Oct'91	22Oct'91
	Species	core 1	core 2	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3
TURBELLARIA	Turbellarians		7	4	9	12	4			5	2	1	7	3	11
OLIGOCHAETA	Oligochaetes	11	19	45	94	59	11	3	7	18	13	10	37	35	15
POLYCHAETA	*Capitella capitata*		3		7	2		1	2		2	3	5	6	2
	Fabricia sabella				1	1				1	1				
	Mediomastus ambiseta	7					1								
	Nereis sp.			1	2	3									
	Pholoe minuta				1										
	Polycirrus eximius				1						1			1	
	Polydora ligni	1	2	10	13	12	8	7	6	9	5	10	11	3	4
	Pygospio elegans		1	20	1	40	8	3	2	1	1		4	3	
	Scoloplos sp.	10	13	3	5	4		2	1	10	13	7			1
	Streblospio benedicti	3	5	6	1	1	3	6	1	14	14	13	7	6	3
	Tharyx acutus	9	13	21	9	7	12	7	15	20	19	13	51	33	35
	Unknown Polychaetes			11	9	12			1	3			18		
BIVALVIA	*Gemma gemma*	27	26	1		5	9	9	6	6	10	10	83	40	49
	Mya arenaria				1			1							
	Tellina agilis	1													
	Unknown Bivalves				1										
GASTROPODA	*Hydrobia minuta*	16	5		3	4		3	2	11	2	14	19		11
	Unknown Gastropods			1			3							4	
AMPHIPODA	*Corophium volutator*								1						
	Gammarus mucronatus														
	Gammarus tigrinus														
	Gammarus sp.				3										
	Unknown Amphipods														
MYSIDACEA	*Neomysis americana*					1			1						
DECAPODA	*Crangon septemspinosa*	1	1				1								
INSECTA	Chironomidae larvae														
	Chironomidae pupae														
	Heleidae larvae														
	Unknown Insects	1		1	3	1									
OTHER	Unknown Organisms			2	1								15		
	Total Turbellaria	0	7	4	9	12	4	0	0	5	2	1	7	3	11
	Total Oligochaeta	11	19	45	94	59	11	3	7	18	13	10	37	35	15
	Total Polychaeta	30	37	72	50	82	32	26	28	58	56	46	96	52	45
	Total Bivalvia	28	26	1	2	5	9	10	6	6	10	10	83	40	49
	Total Gastropoda	16	5	1	3	4	3	3	2	11	2	14	19	4	11
	Total Amphipoda	0	0	0	3	0	0	0	1	0	0	0	0	0	0
	Total Mysidacea	0	0	0	0	1	0	0	1	0	0	0	0	0	0
	Total Decapoda	1	1	0	0	0	1	0	0	0	0	0	0	0	0
	Total Insecta	1	0	1	3	1	0	0	0	0	0	0	0	0	0
	Total Other Orgs.	0	0	2	1	0	0	0	0	0	0	0	15	0	0
	Total Organisms	87	95	126	165	164	60	42	45	98	83	81	257	134	131
	Number of species	11	11	13	19	15	10	10	12	11	12	9	11	10	9
	Total per m2	42924	46871	62166	81408	80914	29603	20722	22202	48351	40951	39964	126799	66113	64633
	Ave. of 2 or 3 cores/m2	44898		74829			24176			43089			85848		

Table 24. (continued).

Species	12May'92 core 1	12May'92 core 2	12May'92 core 3	23July'92 core 1	23July'92 core 2	23July'92 core 3	20Aug'92 core 1	20Aug'92 core 2	20Aug'92 core 3
Turbellarians	8	7	11	3	5	2	2	2	9
Oligochaetes	13	13	19	11	37	14	15	10	17
Capitella capitata		2	1	21	12	18	3	18	2
Fabricia sabella		1							1
Mediomastus ambiseta									
Nereis sp.					1	1			
Pholoe minuta									1
Polycirrus eximius	1								
Polydora ligni	3	4	3	4	3	4	1	3	3
Pygospio elegans	28	32	59	7	12	1	3	5	6
Scoloplos sp.	2	6	4			10		2	
Streblospio benedicti	9	18	15		2	3	3	1	1
Tharyx acutus	2	15	3	1	5	2		3	7
Unknown Polychaetes		17			2	1	1	1	
Gemma gemma	13	18	6	28	17	6	21	30	25
Mya arenaria									
Tellina agilis									
Unknown Bivalves									
Hydrobia minuta	9	11	3		1	2	1		
Unknown Gastropods				2					
Corophium volutator									
Gammarus mucronatus									
Gammarus tigrinus									
Gammarus sp.									
Unknown Amphipods	7								
Neomysis americana									
Crangon septemspinosa									
Chironomidae larvae									
Chironomidae pupae									
Heleidae larvae									
Unknown Insects	2	2							
Unknown Organisms									
Total Turbellaria	8	7	11	3	5	2	2	2	9
Total Oligochaeta	13	13	19	11	37	14	15	10	17
Total Polychaeta	45	95	85	33	37	40	11	33	21
Total Bivalvia	13	18	6	28	17	6	21	30	25
Total Gastropoda	9	11	3	2	1	2	1	0	0
Total Amphipoda	7	0	0	0	0	0	0	0	0
Total Mysidacea	0	0	0	0	0	0	0	0	0
Total Decapoda	0	0	0	0	0	0	0	0	0
Total Insecta	2	2	0	0	0	0	0	0	0
Total Other Orgs	0	0	0	0	0	0	0	0	0
Total Organisms	97	146	124	77	97	64	50	75	72
Number of species	12	13	10	8	11	12	9	10	10
Total per m2	47858	72033	61179	37990	47858	31576	24669	37004	35523
Ave. of 2 or 3 cores/m2	60357			39141			32399		
± standard error	±6991			±4735			±3888		

Species	Summary Information Ave./21 cores	Ave. per m2	% of total
Turbellarians	5.1	2514	4.9
Oligochaetes	23.6	11653	22.7
Capitella capitata	5.1	2514	4.9
Fabricia sabella	0.3	141	0.3
Mediomastus ambiseta	0.0	23	0.0
Nereis sp.	0.4	188	0.4
Pholoe minuta	0.1	47	0.1
Polycirrus eximius	0.2	94	0.2
Polydora ligni	6.0	2960	5.8
Pygospio elegans	11.2	5545	10.8
Scoloplos sp.	3.3	1645	3.2
Streblospio benedicti	6.0	2984	5.8
Tharyx acutus	13.3	6578	12.8
Unknown Polychaetes	3.6	1786	3.5
Gemma gemma	18.7	9210	17.9
Mya arenaria	0.1	47	0.1
Tellina agilis	0.0	0	0.0
Unknown Bivalves	0.0	23	0.0
Hydrobia minuta	4.6	2255	4.4
Unknown Gastropods	0.5	235	0.5
Corophium volutator	0.0	23	0.0
Gammarus mucronatus	0.0	0	0.0
Gammarus tigrinus	0.0	0	0.0
Gammarus sp.	0.1	70	0.1
Unknown Amphipods	0.3	164	0.3
Neomysis americana	0.1	47	0.1
Crangon septemspinosa	0.0	23	0.0
Chironomidae larvae	0.0	0	0.0
Chironomidae pupae	0.0	0	0.0
Heleidae larvae	0.0	0	0.0
Unknown Insects	0.4	211	0.4
Unknown Organisms	0.9	423	0.8
	104.1	51405	100.0
Total Turbellaria	5.1	2514	4.9
Total Oligochaeta	23.6	11653	22.7
Total Polychaeta	49.7	24505	47.7
Total Bivalvia	18.8	9280	18.1
Total Gastropoda	5.0	2490	4.8
Total Amphipoda	0.5	258	0.5
Total Mysidacea	0.1	47	0.1
Total Decapoda	0.0	23	0.0
Total Insecta	0.4	211	0.4
Total Other Orgs.	0.9	423	0.8
Total Organisms	104.2	51405	100.0
Number of species	11.2		

Table 25. Station 3, Bass Harbor Marsh, small core data.

		4Oct'90	4Oct'90	16May'91	16May'91	16May'91	19June'91	19June'91	19June'91	10Sept'91	10Sept'91	10Sept'91	22Oct'91	22Oct'91	22Oct'91
	Species	core 1	core 2	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3
TURBELLARIA	Turbellarians	1	1	25	9	25	9	4	29	1		1	2		1
OLIGOCHAETA	Oligochaetes			1	33	26			35						
POLYCHAETA	*Capitella capitata*			15	54	8	62	5	66	4	15	5	2		
	Fabricia sabella			1						2	1				
	Mediamastus ambiseta														
	Nereis sp.					1			1						
	Pholae minuta														
	Polycirrus eximius														
	Palydora ligni			6	24	3	16	2	23	1					
	Pygaspia elegans														
	Scolaplos sp.			2	1										
	Streblaspia benedicti			16	4	17	99	13	107	5	10	4	1	3	5
	Tharyx acutus														
	Unknown Polychaetes			12	7	1		4	8	1					
BIVALVIA	*Gemma gemma*														
	Mya arenaria														
	Tellina agilis														
	Unknown Bivalves														
GASTROPODA	*Hydrabia minuta*	27	33	11	32	20	32	8	66	98	82	18	150	7	14
	Unknown Gastropods														
AMPHIPODA	*Caraphium valutatar*														
	Gammarus mucranatus								1						
	Gammarus tigrinus														
	Gammarus sp.					1									
	Unknown Amphipods		1	2	7										
MYSIDACEA	*Neamysis americana*														
DECAPODA	*Crangan septemspinasa*														
INSECTA	Chironomidae larvae	2	3		1	1	13	8	7	1	5	4	1	2	1
	Chironomidae pupae														
	Heleidae larvae														
	Unknown Insects	1							1						
OTHER	Unknown Organisms														
	-														
	Total Turbellaria	1	1	25	9	25	9	4	29	1	0	1	2	0	1
	Total Oligochaeta	0	0	1	33	26	0	0	35	0	0	0	0	0	0
	Total Polychaeta	0	0	52	90	30	177	24	205	13	26	9	3	3	5
	Total Bivalvia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gastropoda	27	33	11	32	20	32	8	66	98	82	18	150	7	14
	Total Amphipoda	0	1	2	7	1	0	0	1	0	0	0	0	0	0
	Total Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Decapoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Insecta	3	3	0	1	1	13	8	8	1	5	4	1	2	1
	Total Other Orgs.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Organisms	31	38	91	172	103	231	44	344	113	113	32	156	12	21
	Number of species	4	4	10	10	10	6	7	11	8	5	5	5	3	4
	Total per m2	15295	18748	44898	84861	50818	113971	21709	169723	55752	55752	15788	76967	5921	10361
	Ave. of 2 or 3 cores/m2	17022		60192			101801			42431			31083		

Table 25. (continued).

Species	12May'92 core 1	12May'92 core 2	12May'92 core 3	23July'92 core 1	23July'92 core 2	23July'92 core 3	20Aug'92 core 1	20Aug'92 core 2	20Aug'92 core 3
Turbellarians		4	5	2	2		15	16	23
Oligochaetes			3	8	1	4	1		3
Capitella capitata		12		49	12	19	14	11	6
Fabricia sabella									
Mediomastus ambiseta									
Nereis sp.		7							
Pholoe minuta									
Polycirrus eximius									
Polydora ligni				3		1	2	4	2
Pygospio elegans									
Scoloplos sp.					1				
Streblospio benedicti		1	3	8	4	13	21	16	23
Tharyx acutus									
Unknown Polychaetes									
Gemma gemma									
Mya arenaria									
Tellina agilis									
Unknown Bivalves						2			
Hydrobia minuta	2	42	65	25	11	17	51	44	65
Unknown Gastropods									
Corophium volutator									
Gammarus mucronatus									
Gammarus tigrinus									
Gammarus sp.									
Unknown Amphipods									
Neomysis americana									
Crangon septemspinosa									
Chironomidae larvae				7	3			3	1
Chironomidae pupae									
Heleidae larvae									
Unknown Insects									
Unknown Organisms						1			
Total Turbellaria	0	4	5	2	2	0	15	16	23
Total Oligochaeta	0	0	3	8	1	4	1	0	3
Total Polychaeta	0	20	3	60	17	33	37	31	31
Total Bivalvia	0	0	0	0	0	2	0	0	0
Total Gastropoda	2	42	65	25	11	17	51	44	65
Total Amphipoda	0	0	0	0	0	0	0	0	0
Total Mysidacea	0	0	0	0	0	0	0	0	0
Total Decapoda	0	0	0	0	0	0	0	0	0
Total Insecta	0	0	0	7	3	0	0	3	1
Total Other Orgs.	0	0	0	0	0	1	0	0	0
Total Organisms	2	66	76	102	34	57	104	94	123
Number of species	1	5	4	7	7	7	6	6	7
Total per m2	987	32563	37497	50325	16775	28123	51312	46378	60686
Ave. of 2 or 3 cores/m2	23682			31741			52792		
± standard error	±11437			±9853			±4196		

Species	Summary Information Ave./21 cores	Ave. per m2	% of total
Turbellarians	8.2	4065	8.3
Oligochaetes	5.5	2702	5.5
Capitella capitata	17.1	8434	17.2
Fabricia sabella	0.2	94	0.2
Mediomastus ambiseta	0.0	0	0.0
Nereis sp.	0.4	211	0.4
Pholoe minuta	0.0	0	0.0
Polycirrus eximius	0.0	0	0.0
Polydora ligni	4.1	2044	4.2
Pygospio elegans	0.0	0	0.0
Scoloplos sp.	0.2	94	0.2
Streblospio benedicti	17.8	8763	17.8
Tharyx acutus	0.0	0	0.0
Unknown Polychaetes	1.6	775	1.6
Gemma gemma	0.0	0	0.0
Mya arenaria	0.0	0	0.0
Tellina agilis	0.0	0	0.0
Unknown Bivalves	0.1	47	0.1
Hydrobia minuta	41.0	20205	41.1
Unknown Gastropods	0.0	0	0.0
Corophium volutator	0.0	0	0.0
Gammarus mucronatus	0.0	23	0.0
Gammarus tigrinus	0.0	0	0.0
Gammarus sp.	0.0	23	0.0
Unknown Amphipods	0.4	211	0.4
Neomysis americana	0.0	0	0.0
Crangon septemspinosa	0.0	0	0.0
Chironomidae larvae	2.8	1363	2.8
Chironomidae pupae	0.0	0	0.0
Heleidae larvae	0.0	0	0.0
Unknown Insects	0.0	23	0.0
Unknown Organisms	0.0	23	0.0
	99.5	49103	100.0
Total Turbellaria	8.2	4065	8.3
Total Oligochaeta	5.5	2702	5.5
Total Polychaeta	41.4	20417	41.6
Total Bivalvia	0.1	47	0.1
Total Gastropoda	41.0	20205	41.1
Total Amphipoda	0.5	258	0.5
Total Mysidacea	0.0	0	0.0
Total Decapoda	0.0	0	0.0
Total Insecta	2.8	1386	2.8
Total Other Orgs.	0.0	23	0.0
Total Organisms	99.5	49103	100.0
Number of species	6.4		

Table 26. Station 6, Bass Harbor Marsh, small core data.

		4Oct'90	4Oct'90	16May'91	16May'91	16May'91	19June'91	19June'91	19June'91	10Sept'91	10Sept'91	10Sept'91	23Oct'91	23Oct'91	23Oct'91
	Species	no cores		core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3
TURBELLARIA	Turbellarians			7	9	6	5	9	16		1	1			
OLIGOCHAETA	Oligochaetes			2	6	6	1	2	2						
POLYCHAETA	*Capitella capitata*														
	Fabricia sabella														
	Mediomastus ambiseta														
	Nereis sp.														
	Pholoe minuta														
	Polycirrus eximius														
	Polydora ligni								2						
	Pygospio elegans														
	Scoloplos sp.														
	Streblospio benedicti														
	Tharyx acutus														
	Unknown Polychaetes								1	1					
BIVALVIA	*Gemma gemma*														
	Mya arenaria														
	Tellina agilis														
	Unknown Bivalves														
GASTROPODA	*Hydrobia minuta*														
	Unknown Gastropods											1			
AMPHIPODA	*Corophium volutator*														
	Gammarus mucronatus				1				4	2					
	Gammarus tigrinus			11	3	43			3	1					
	Gammarus sp.						2								
	Unknown Amphipods														
MYSIDACEA	*Neomysis americana*														
DECAPODA	*Crangon septemspinosa*														
INSECTA	Chironomidae larvae			10	15	12	10	5	4	35	30	16	22	38	46
	Chironomidae pupae				1	4									
	Heleidae larvae														
	Unknown Insects														
OTHER	Unknown Organisms														
	Total Turbellaria			7	9	6	5	9	16	0	1	1	0	0	0
	Total Oligochaeta			2	6	6	1	2	2	0	0	0	0	0	0
	Total Polychaeta			0	0	0	0	0	3	1	0	0	0	0	0
	Total Bivalvia			0	0	0	0	0	0	0	0	0	0	0	0
	Total Gastropoda			0	0	0	0	0	0	0	1	0	0	0	0
	Total Amphipoda			11	4	43	2	7	3	0	0	0	0	0	0
	Total Mysidacea			0	0	0	0	0	0	0	0	0	0	0	0
	Total Decapoda			0	0	0	0	0	0	0	0	0	0	0	0
	Total Insecta			10	16	16	10	5	4	35	30	16	22	38	46
	Total Other Orgs.			0	0	0	0	0	0	0	0	0	0	0	0
	Total Organisms			30	35	71	18	23	28	36	32	17	22	38	46
	Number of species			4	5	4	4	4	7	2	3	2	1	1	1
	Total per m2			14801	17268	35030	8881	11348	13815	17762	15788	8387	10854	18748	22695
	Ave. of 3 cores/m2			22367			11348			13979			17433		

Table 26. (continued).

Species	12May'92 core 1	12May'92 core 2	12May'92 core 3	23July'92 core 1	23July'92 core 2	23July'92 core 3	20Aug'92 core 1	20Aug'92 core 2	20Aug'92 core 3
Turbellarians				5	6	7		1	
Oligochaetes	12	11	6			2		1	
Capitella capitata									
Fabricia sabella									
Mediomastus ambiseta									
Nereis sp.									
Pholoe minuta									
Polycirrus eximius									
Polydora ligni									
Pygospio elegans									
Scoloplos sp.									
Streblospio benedicti									
Tharyx acutus									
Unknown Polychaetes	9								
Gemma gemma									
Mya arenaria									
Tellina agilis									
Unknown Bivalves									
Hydrobia minuta									
Unknown Gastropods									
Corophium volutator									
Gammarus mucronatus									
Gammarus tigrinus									
Gammarus sp.	2							1	
Unknown Amphipods									
Neomysis americana									
Crangon septemspinosa									
Chironomidae larvae	32	4	10	39	70	43	65	58	52
Chironomidae pupae						2			
Heleidae larvae									
Unknown Insects								1	2
Unknown Organisms									
Total Turbellaria	0	0	0	5	6	7	0	1	0
Total Oligochaeta	12	11	6	0	0	2	0	1	0
Total Polychaeta	9	0	0	0	0	0	0	0	0
Total Bivalvia	0	0	0	0	0	0	0	0	0
Total Gastropoda	0	0	0	0	0	0	0	0	0
Total Amphipoda	2	0	0	0	0	0	0	1	0
Total Mysidacea	0	0	0	0	0	0	0	0	0
Total Decapoda	0	0	0	0	0	0	0	0	0
Total Insecta	32	4	10	39	70	45	65	59	54
Total Other Orgs.	0	0	0	0	0	0	0	0	0
Total Organisms	55	15	16	44	76	54	65	62	54
Number of species	4	2	2	2	2	3	1	5	2
Total per m2	27136	7401	7894	21709	37497	26643	32070	30590	26643
Ave. of 3 cores/m2	14144			28616			29767		
± standard error	±6498			±4663			±1620		

Species	Summary Information Ave./21 cores	Ave. per m2	% of total
Turbellarians	3.5	1715	8.7
Oligochaetes	2.4	1198	6.1
Capitella capitata	0.0	0	0.0
Fabricia sabella	0.0	0	0.0
Mediomastus ambiseta	0.0	0	0.0
Nereis sp.	0.0	0	0.0
Pholoe minuta	0.0	0	0.0
Polycirrus eximius	0.0	0	0.0
Polydora ligni	0.1	47	0.2
Pygospio elegans	0.0	0	0.0
Scoloplos sp.	0.0	0	0.0
Streblospio benedicti	0.0	0	0.0
Tharyx acutus	0.0	0	0.0
Unknown Polychaetes	0.5	258	1.3
Gemma gemma	0.0	0	0.0
Mya arenaria	0.0	0	0.0
Tellina agilis	0.0	0	0.0
Unknown Bivalves	0.0	0	0.0
Hydrobia minuta	0.0	0	0.0
Unknown Gastropods	0.0	23	0.1
Corophium volutator	0.0	0	0.0
Gammarus mucronatus	0.3	164	0.8
Gammarus tigrinus	2.9	1433	7.3
Gammarus sp.	0.2	117	0.6
Unknown Amphipods	0.0	0	0.0
Neomysis americana	0.0	0	0.0
Crangon septemspinosa	0.0	0	0.0
Chironomidae larvae	29.3	14472	73.6
Chironomidae pupae	0.3	164	0.8
Heleidae larvae	0.0	0	0.0
Unknown Insects	0.1	70	0.4
Unknown Organisms	0.0	0	0.0
	39.9	19665	100.0
Total Turbellaria	3.5	1715	8.7
Total Oligochaeta	2.4	1198	6.1
Total Polychaeta	0.6	305	1.6
Total Bivalvia	0.0	0	0.0
Total Gastropoda	0.0	23	0.1
Total Amphipoda	3.5	1715	8.7
Total Mysidacea	0.0	0	0.0
Total Decapoda	0.0	0	0.0
Total Insecta	29.8	14707	74.8
Total Other Orgs.	0.0	0	0.0
Total Organisms	39.9	19665	100.0
Number of species	2.9		

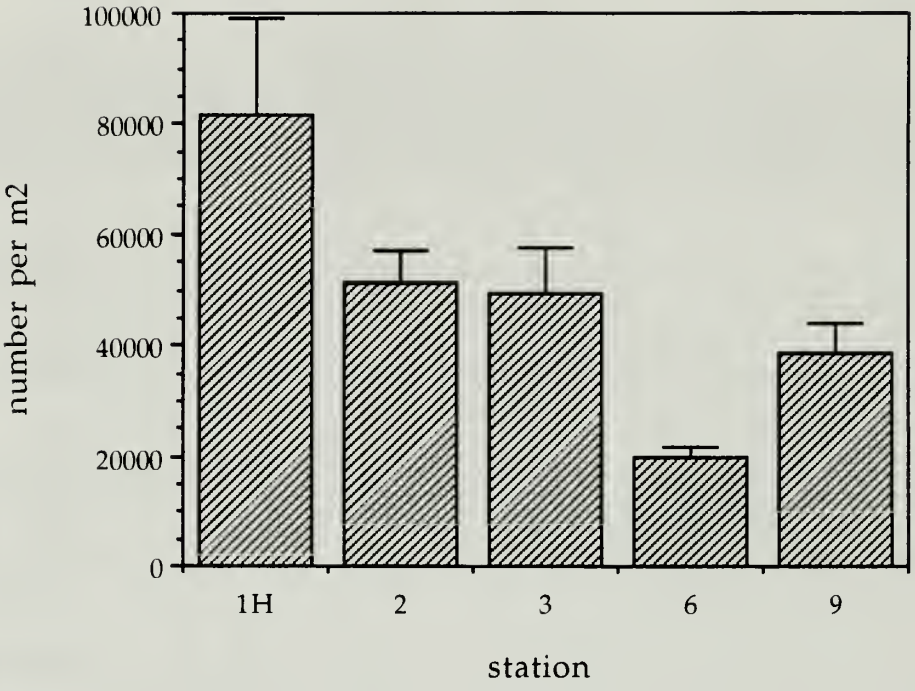


Fig. 33. Total benthic macrofaunal abundance per station, averaged over 1991-1992 sampling dates. ± standard error.

Table 27. Station 9, Bass Harbor Marsh, small core data.

		4Oct'90	4Oct'90	16May'91	16May'91	16May'91	19June'91	19June'91	19June'91	10Sept'91	10Sept'91	10Sept'91	23Oct'91	23Oct'91	23Oct'91
	Species	core 1	core 2	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3	core 1	core 2	core 3
TURBELLARIA	Turbellarians			1											
OLIGOCHAETA	Oligochaetes	2	12	7	13	55	1		9	6	1		5		
POLYCHAETA	*Capitella capitata*														
	Fabricia sabella														
	Mediomastus ambiseta														
	Nereis sp.														
	Pholoe minuta														
	Polycirrus eximius														
	Polydora ligni														
	Pygospio elegans														
	Scoloplos sp.														
	Streblospio benedicti														
	Tharyx acutus														
	Unknown Polychaetes	2			1										
BIVALVIA	*Gemma gemma*														
	Mya arenaria														
	Tellina agilis														
	Unknown Bivalves														
GASTROPODA	*Hydrobia minuta*														
	Unknown Gastropods						1								
AMPHIPODA	*Corophium volutator*														
	Gammarus mucronatus														
	Gammarus tigrinus	10	45	3		1	30	58	78	3			1		
	Gammarus sp.														
	Unknown Amphipods														
MYSIDACEA	*Neomysis americana*														
DECAPODA	*Crangon septemspinosa*														
INSECTA	Chironomidae larvae	52	61	15	14	12	8	11	24	22	42	47	62	58	68
	Chironomidae pupae	1			2	2				1					
	Heleidae larvae	1	4			2			2						1
	Unknown Insects							1	2	1					
OTHER	Unknown Organisms	1				1									
	Total Turbellaria	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Total Oligochaeta	2	12	7	13	55	1	0	9	6	1	0	5	0	0
	Total Polychaeta	2	0	0	1	0	0	0	0	0	0	0	0	0	0
	Total Bivalvia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gastropoda	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Total Amphipoda	10	45	3	0	1	30	58	78	3	0	0	1	0	0
	Total Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Decapoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Insecta	54	65	15	16	16	8	12	28	24	42	47	62	58	69
	Total Other Orgs.	1	0	0	0	1	0	0	0	0	0	0	0	0	0
	Total Organisms	69	122	26	30	73	40	70	115	33	43	47	68	58	69
	Number of species	6	4	4	3	5	4	3	5	4	2	1	3	1	2
	Total per m2	34043	60192	12828	14801	36017	19735	34537	56739	16282	21215	23189	33550	28616	34043
	Ave. of 2 or 3 cores/m2	47118		21215			37004			20229			32070		
	± standard error	±13075		±7423			±10753			±2054			±1733		

Table 27. (continued).

Species	12May'92 core 1	12May'92 core 2	12May'92 core 3	23July'92 core 1	23July'92 core 2	23July'92 core 3	20Aug'92 core 1	20Aug'92 core 2	20Aug'92 core 3
Turbellarians				3					
Oligochaetes	15	70	62	32	4	12			
Capitella capitata									
Fabricia sabella									
Mediomastus ambiseta									
Nereis sp.									
Pholoe minuta									
Polycirrus eximius									
Polydora ligni									
Pygospio elegans									
Scoloplos sp.									
Streblospio benedicti									
Tharyx acutus									
Unknown Polychaetes									
Gemma gemma									
Mya arenaria									
Tellina agilis									
Unknown Bivalves									
Hydrobia minuta									
Unknown Gastropods									
Corophium volutator									
Gammarus mucronatus									
Gammarus tigrinus				5	2				
Gammarus sp.									
Unknown Amphipods									
Neomysis americana									
Crangon septemspinosa									
Chironomidae larvae	75	155	119	81	60	78	46	45	52
Chironomidae pupae					2	7	1	1	
Heleidae larvae		1							
Unknown Insects	1			3		19			1
Unknown Organisms				15					
Total Turbellaria	0	0	0	3	0	0	0	0	0
Total Oligochaeta	15	70	62	32	4	12	0	0	0
Total Polychaeta	0	0	0	0	0	0	0	0	0
Total Bivalvia	0	0	0	0	0	0	0	0	0
Total Gastropoda	0	0	0	0	0	0	0	0	0
Total Amphipoda	0	0	0	5	2	0	0	0	0
Total Mysidacea	0	0	0	0	0	0	0	0	0
Total Decapoda	0	0	0	0	0	0	0	0	0
Total Insecta	76	156	119	84	62	104	47	46	53
Total Other Orgs.	0	0	0	15	0	0	0	0	0
Total Organisms	91	226	181	139	68	116	47	46	53
Number of species	3	3	2	6	3	3	1	1	2
Total per m2	44898	111504	89302	68580	33550	57232	23189	22695	26149
Ave. of 2 or 3 cores/m2	81901			53121			24011		

Species	Summary Information Ave./21 cores	Ave. per m2	% of total
Turbellarians	0.2	94	0.2
Oligochaetes	13.9	6860	17.8
Capitella capitata	0.0	0	0.0
Fabricia sabella	0.0	0	0.0
Mediomastus ambiseta	0.0	0	0.0
Nereis sp.	0.0	0	0.0
Pholoe minuta	0.0	0	0.0
Polycirrus eximius	0.0	0	0.0
Polydora ligni	0.0	0	0.0
Pygospio elegans	0.0	0	0.0
Scoloplos sp.	0.0	0	0.0
Streblospio benedicti	0.0	0	0.0
Tharyx acutus	0.0	0	0.0
Unknown Polychaetes	0.0	23	0.1
Gemma gemma	0.0	0	0.0
Mya arenaria	0.0	0	0.0
Tellina agilis	0.0	0	0.0
Unknown Bivalves	0.0	0	0.0
Hydrobia minuta	0.0	0	0.0
Unknown Gastropods	0.0	23	0.1
Corophium volutator	0.0	0	0.0
Gammarus mucronatus	0.0	0	0.0
Gammarus tigrinus	8.6	4252	11.0
Gammarus sp.	0.0	0	0.0
Unknown Amphipods	0.0	0	0.0
Neomysis americana	0.0	0	0.0
Crangon septemspinosa	0.0	0	0.0
Chironomidae larvae	52.1	25703	66.7
Chironomidae pupae	0.8	376	1.0
Heleidae larvae	0.3	141	0.4
Unknown Insects	1.3	658	1.7
Unknown Organisms	0.8	376	1.0
	78.0	38507	100.0
Total Turbellaria	0.2	94	0.2
Total Oligochaeta	13.9	6860	17.8
Total Polychaeta	0.0	23	0.1
Total Bivalvia	0.0	0	0.0
Total Gastropoda	0.0	23	0.1
Total Amphipoda	8.6	4252	11.0
Total Mysidacea	0.0	0	0.0
Total Decapoda	0.0	0	0.0
Total Insecta	54.5	26877	69.8
Total Other Orgs.	0.8	376	1.0
Total Organisms	78.0	38507	100.0
Number of species	2.9		

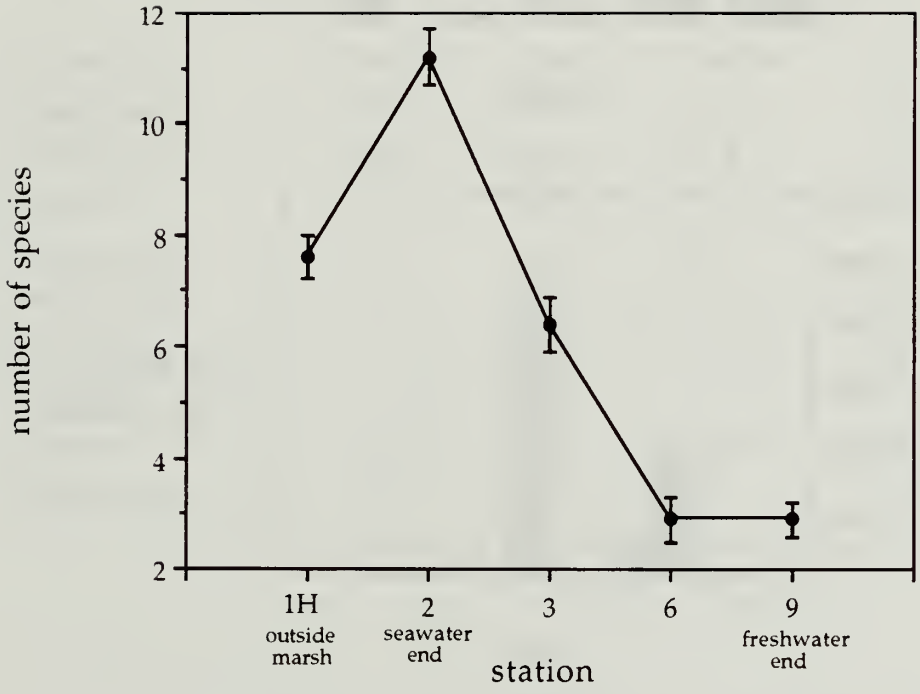


Fig. 34. Number of benthic species per station, averaged over 1991-1992 sampling dates. ± standard error.

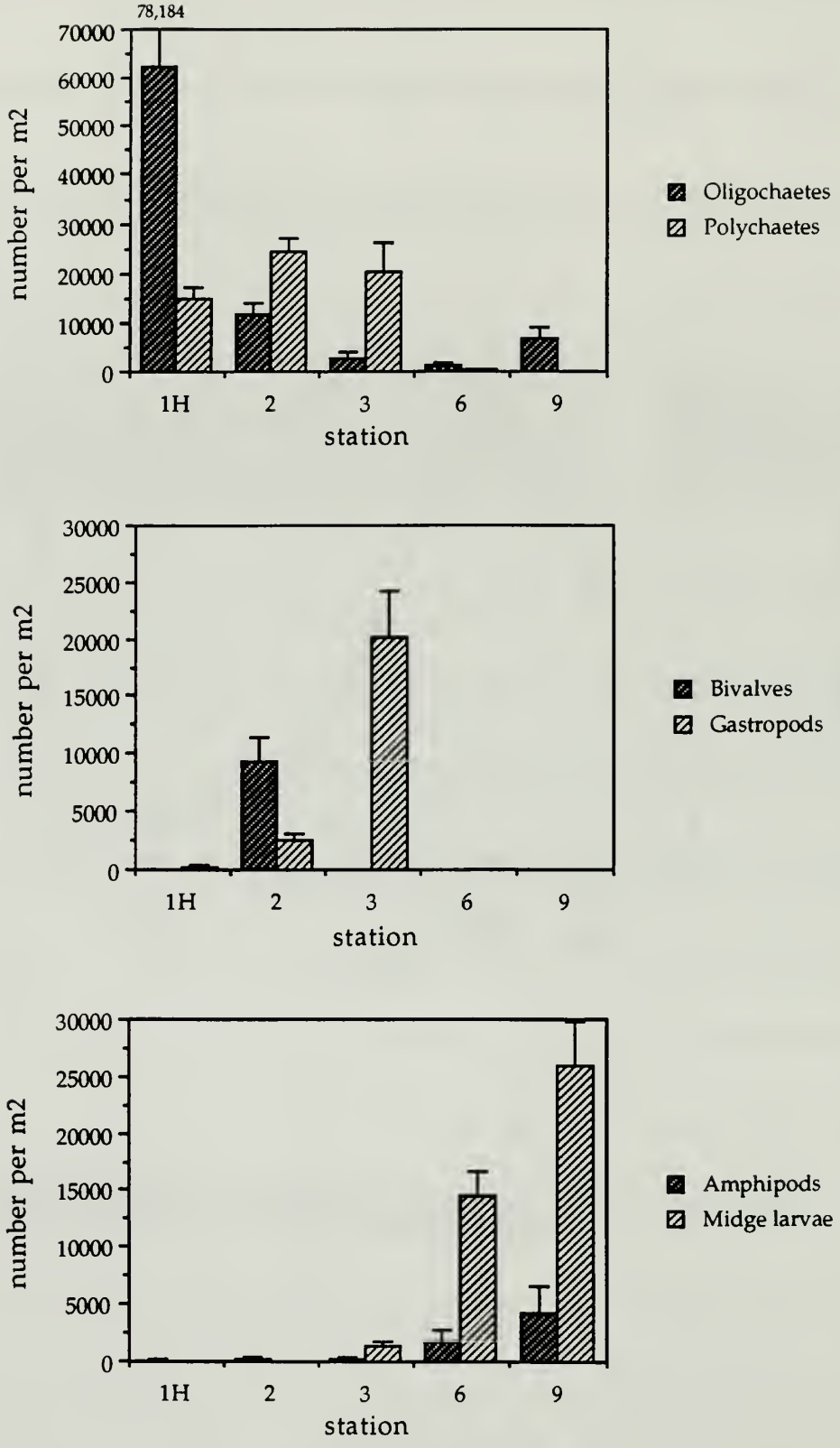


Fig. 35. Abundances of six benthic faunal groups vs station, averaged over 1991-92 sampling dates. ± standard error. Please note that scale is different in top graph.

Table 28. Taxonomic groups expressed as a percent of total benthic macrofauna. 1991 & 1992 data. Dominant (over 5% of total) groups for each station are highlighted.

Group	Sta 1H	Sta 2	Sta 3	Sta 6	Sta 9
Turbellaria	4.3	4.9	**8.3**	**8.7**	0.2
Oligochaeta	**76.4**	**22.7**	**5.5**	**6.1**	**17.8**
Polychaeta	**18.5**	**47.7**	**41.6**	1.6	0.1
Bivalvia	0	**18.1**	0.1	0	0
Gastropoda	0.3	4.8	**41.1**	0.1	0.1
Amphipoda	0.1	0.5	0.5	**8.7**	**11.0**
Mysidacea	0	0.1	0	0	0
Decapoda	0	0	0	0	0
Insecta	0.1	0.4	2.8	**74.8**	**69.8**
Other Orgs.	0.3	0.8	0	0	1.0

lower estuarine stations; and amphipods and particularly midge larvae predominated at the two upper estuarine locations.

Oligochaetes: Oligochaetes were common at all sites in Bass Harbor Marsh, especially at stations 1H and 2 where they were present in every core taken (Tables 23 and 24). Oligochaetes dominated the benthos of station 1H, averaging over 60,000 m^{-2} during the 1991-1992 sampling period (Fig. 35) and accounting for 76.4% of total benthic animals (Table 28). While oligochaetes were much less abundant at stations 2 and 9 compared to station 1H, they were still significant as a percent of total organisms (22.7% and 17.8%, respectively; Table 28).

Polychaetes: Polychaetes were found in greatest numbers at the higher saline stations (1H, 2 and 3) with numbers averaging 15 to 25,000 m^{-2} (Fig. 35). They were very prevalent at these three sites, being present in all cores (with three exceptions for station 3; Tables 23-25). Polychaetes were virtually absent from the upper estuary (stations 6 and 9).

Polychaetes were about equally important at stations 2 and 3 (47.7% and 41.6% of total animals, respectively), decreasing to 18.5% of the total at station 1H (Table 28). Six species were found most often: *Capitella capitata, Polydora ligni, Pygospio elegans, Scoloplos* sp., *Streblospio benedicti,* and *Tharyx acutus* (Tables 23-25, Table 29). Their importance varied by station. At station 1H, *S. benedicti* was most abundant. At station 2, *T. acutus* and *P. elegans* were most numerous although the other four species were still frequently seen. At station 3, *S. benedicti* and *C. capitata* were about equally abundant, with *P. ligni* of lesser importance.

Bivalves: Bivalves were found almost exclusively at station 2, where they averaged 10,000 m^{-2} (Fig. 35) and comprised 18.1% of total animals (Table 28). *Gemma gemma* accounted for 99% of the bivalves sampled and was present in all but one core during the two-year study (Tables 24 and 29).

Gastropods: Gastropods, specifically *Hydrobia minuta,* were a dominate member of the benthos of station 3, present in every core (Table 25). Their average abundance was 20,000 m^{-2} (Fig. 35) which accounted for 41.1% of the benthos at this site (Tables 28 and 29). Gastropods were also frequently found at station 2 (Table 24), though in much reduced numbers (averaging 2,500 m^{-2}; Fig. 35).

Amphipods: Amphipods were more commonly found at the brackish/ freshwater end of the estuary. Although amphipods were only present in half or less of the cores from the upper two sites (Tables 26 and 27) and averaged a modest 2 to 4,000 m^{-2} (Fig. 35), they were proportionately important (8.7% and 11.0% of total animals for stations 6 and 9, respectively; Table 28). *Gammarus tigrinus* was the primary species at both sites, while *G. mucronatus* was occasionally observed at station 6 (Tables 26, 27, and 29).

Table 29. Common (over 1% of total animals) species or groups, expressed as a percent of total benthic macrofauna. 1991 & 1992 data. Dominant (over 5% of total) species for each station are highlighted.

Species or Group	Sta 1H	Sta 2	Sta 3	Sta 6	Sta 9
Turbellaria	4.3	4.9	**8.3**	**8.7**	0.2
Oligochaeta	**76.4**	**22.7**	**5.5**	**6.1**	**17.8**
Polychaeta					
Capitella capitata	2.0	4.9	**17.2**	0	0
Polydora ligni	0.9	**5.8**	4.2	0.2	0
Pygospio elegans	0.3	**10.8**	0	0	0
Scoloplos sp.	1.3	3.2	0.2	0	0
Streblospio benedicti	**9.5**	**5.8**	**17.8**	0	0
Tharyx acutus	2.1	**12.8**	0	0	0
Bivalvia					
Gemma gemma	0	**17.9**	0	0	0
Gastropoda					
Hydrobia minuta	0.2	4.4	**41.1**	0	0
Amphipoda					
Gammarus tigrinus	0	0	0	**7.3**	**11.0**
Insecta					
Chironomidae larvae	0.1	0	2.8	**73.6**	**66.7**

Midge larvae: Midge larvae clearly dominated the benthos of upper estuarine stations 6 and 9, averaging 15 to 25,000 m^{-2} (Fig. 35), and found in every core sampled from these sites (Tables 26 and 27). Larvae from the family Chironomidae were the most common, contributing 73.6% and 66.7% of total organism abundance at stations 6 and 9, respectively (Table 29). Larvae from the family Heleidae were also seen occasionally at station 9 (Table 27).

Turbellarians: Turbellarians (not graphed) were prevalent members of the benthic community at all stations except 9, averaging between ~2 and 4,000 m^{-2} (Tables 23-26) and ranging from 4.3 to 8.7% of total animals (Table 28). They were found in most cores for the lower estuary (stations 1H, 2, and 3; Tables 23-25). Turbellarians were present in only about half of the cores for station 6 (although found during 5 of the 7 sampling periods; Table 26); however, they were still important in a relative sense since total animal numbers were lowest in general at station 6.

Seasonal Distribution Of Benthic Macrofauna

There was not a clear seasonal trend for total benthic macrofauna at the five stations (Fig. 36). Even when abundances of the five sites were averaged, there was not a strong seasonal pattern although highest numbers were observed in May of both years (averaging 60,000 and 80,000^{+} m^{-2} , respectively; Fig. 37). Values for the other six sampling times were fairly comparable, ranging between about 30,000 and 45,000 m^{-2} (Fig. 37).

Station 1H: For station 1H, highest numbers by far were observed in May of 1991 and 1992 (over 120,000 and 230,000 m^{-2}, respectively; Fig. 36). The seasonal pattern for station 1H was primarily driven by abundances of oligochaetes (Fig. 38). This was especially true in the spring of 1991 and again in 1992 when tremendous numbers of juvenile oligochaetes were observed. In May of both years, oligochaetes represented over 80% of total animals. Oligochaetes as a percent of total animal abundance declined steadily throughout the summer and fell to a low of 27% of the total in October.

Station 2: While animal abundances were also high in May of 1991 and 1992 at station 2 (75,000 and 60,000 m^{-2}, respectively), they were greatest in October of 1991 (about 85,000 m^{-2}; Fig. 36). Bivalves peaked in abundance during this month (Fig. 38) and accounted for about one-third of total macrofaunal numbers. The seasonality of polychaete abundances closely mirrored that for total abundance at station 2, with highest numbers in May of both years and October of 1991 (Fig. 38). A peak of oligochaetes in May of 1991 contributed 44% to total abundance at that time (Fig. 38).

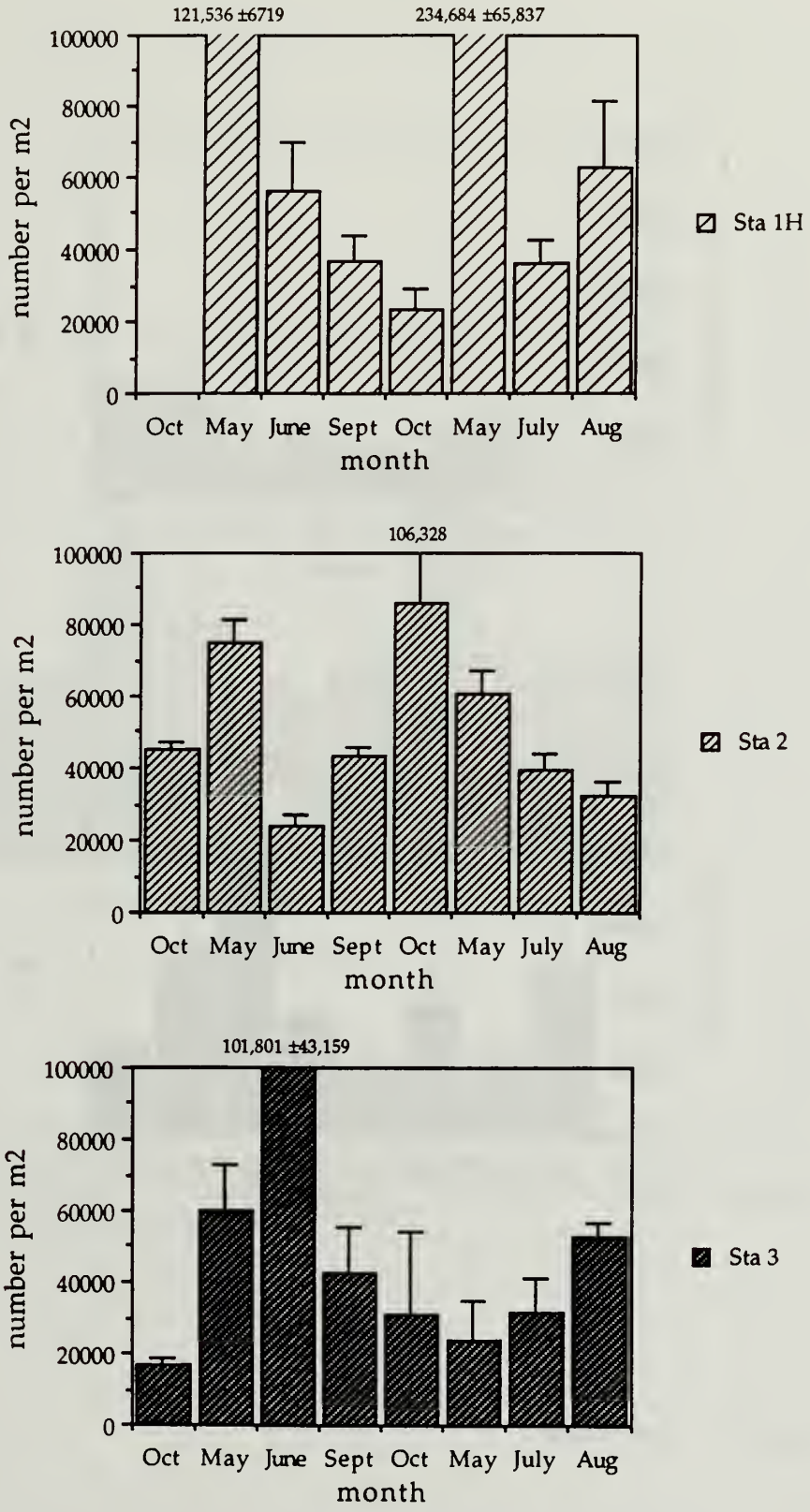
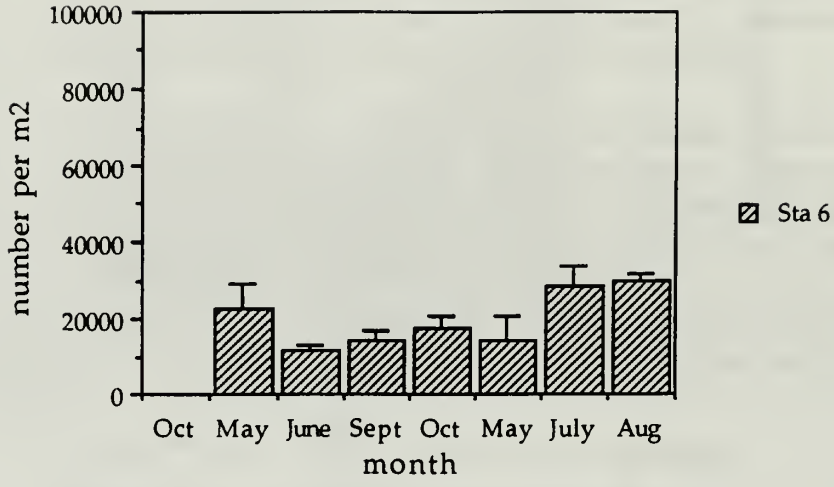


Fig. 36. Total benthic macrofaunal abundance, October 1990 - Aug 1992, by station. ± standard error. All graphs are plotted on the same scale to facilitate comparisons among stations.



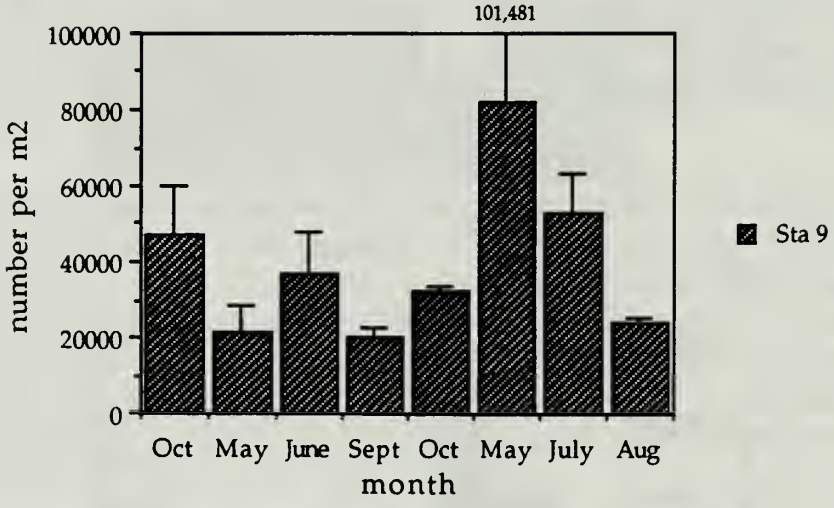


Fig. 36. Continued.

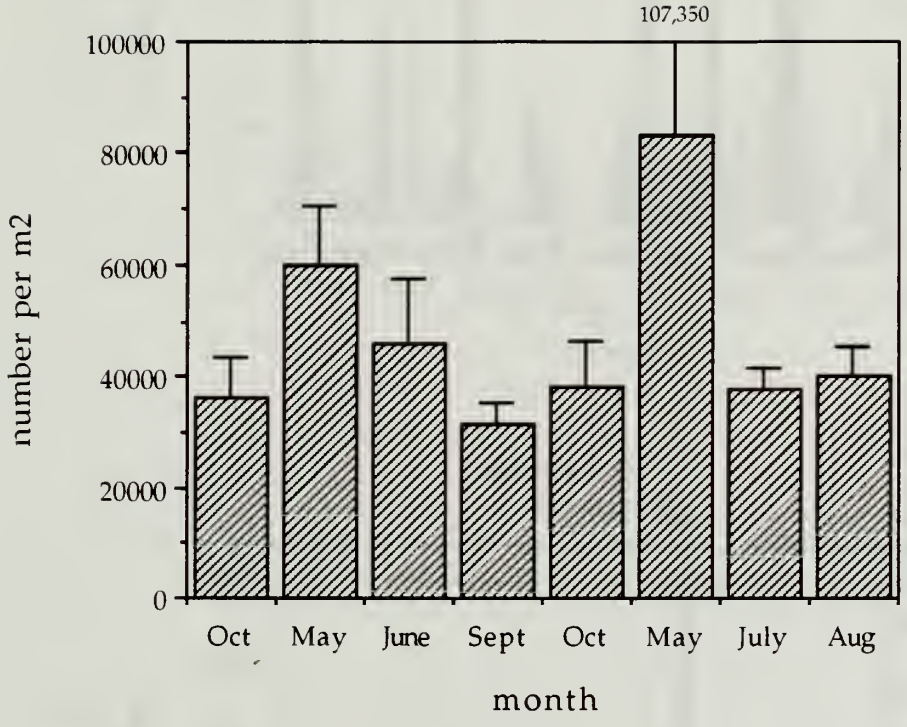


Fig. 37. Total benthic macrofaunal abundance per sample date, October 1990 - Aug. 1992, averaged over the five stations. ± standard error. For October 1990, average of stations 2,3, and 9 only.

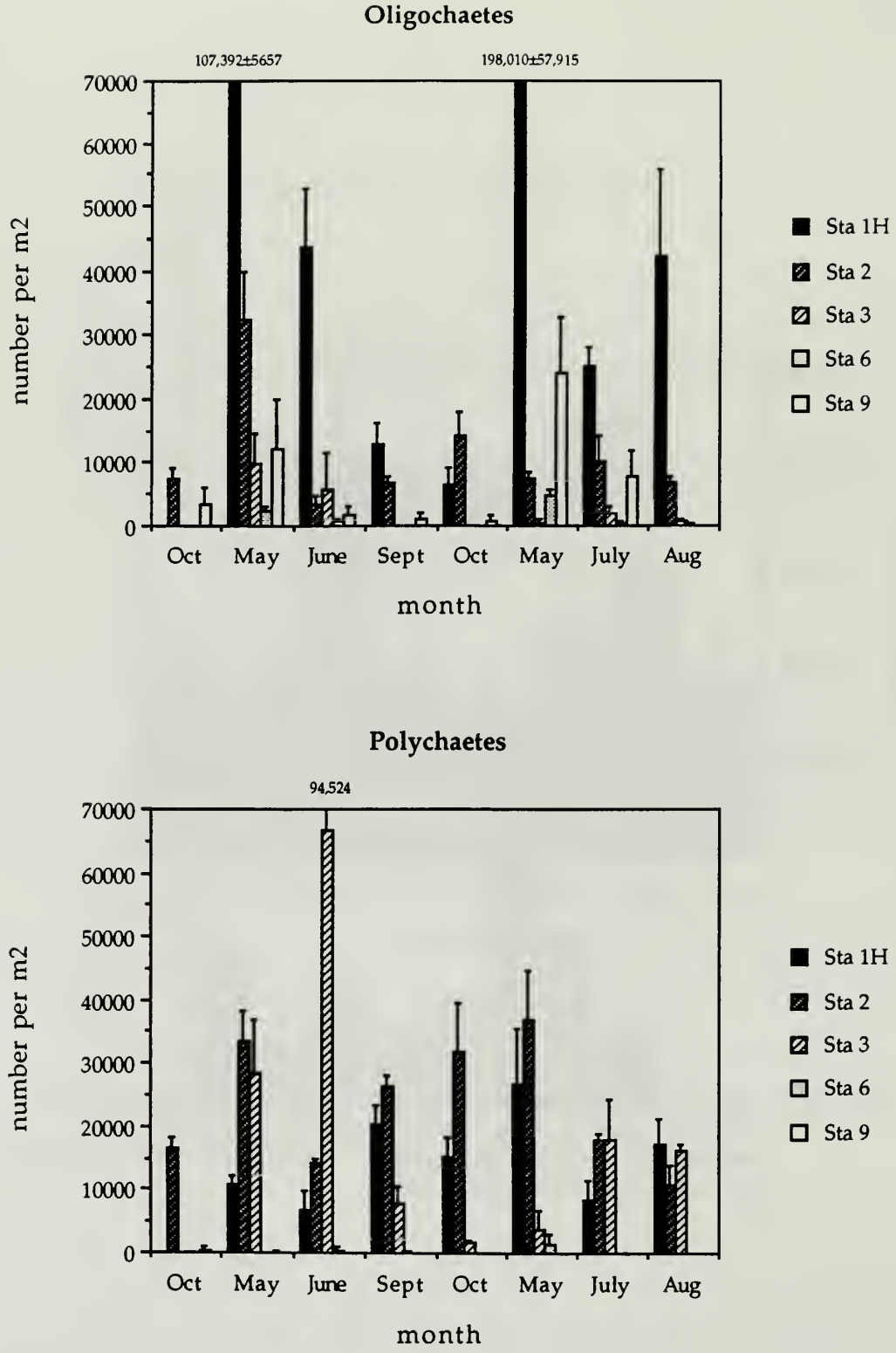
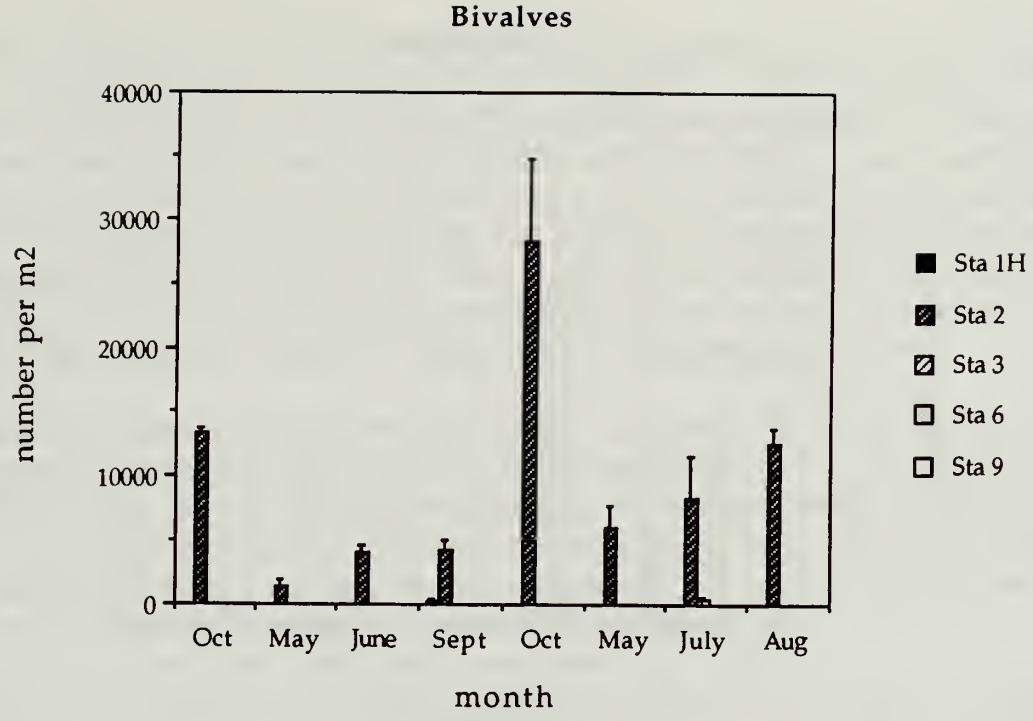


Fig. 38. Abundances of six benthic faunal groups by station, October 1990 - August 1992. ± standard error.



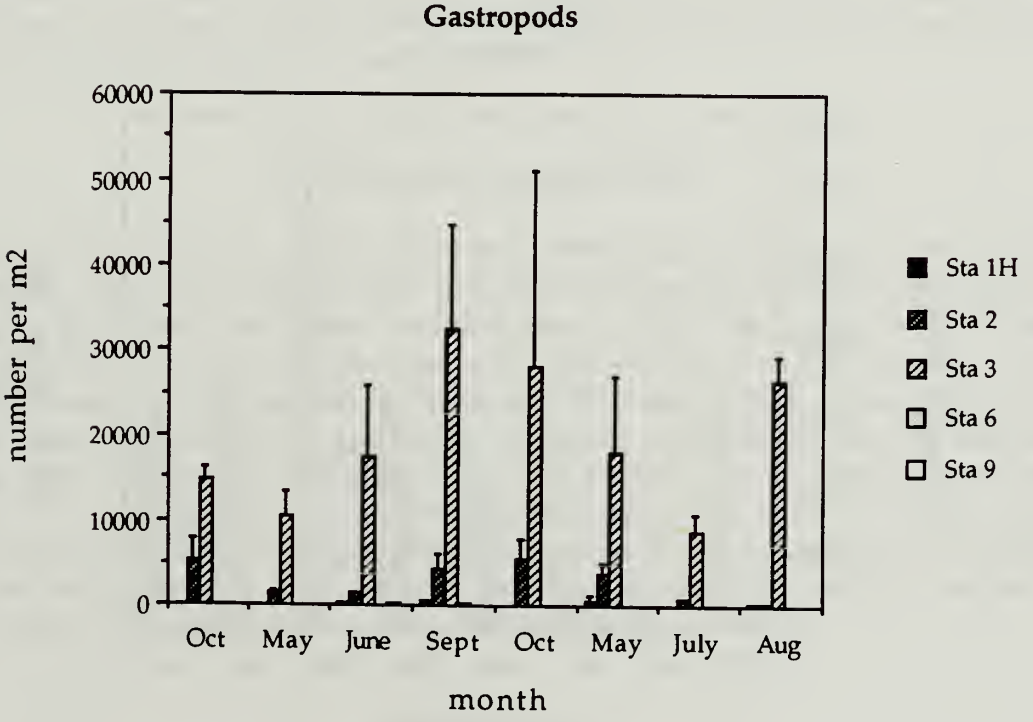
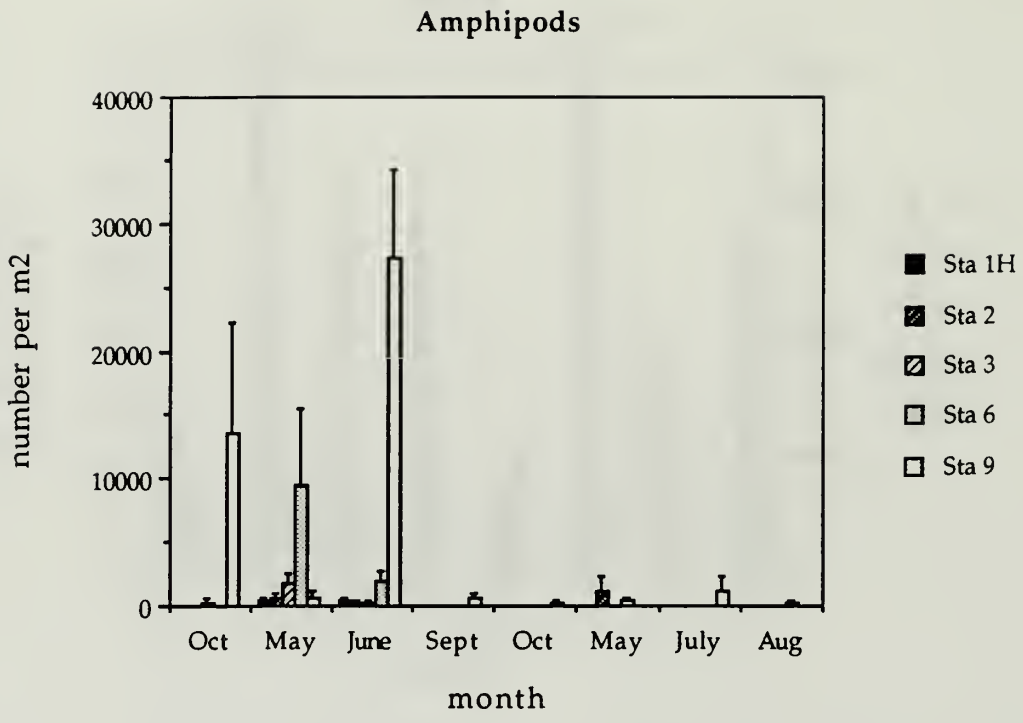


Fig. 38. Continued.



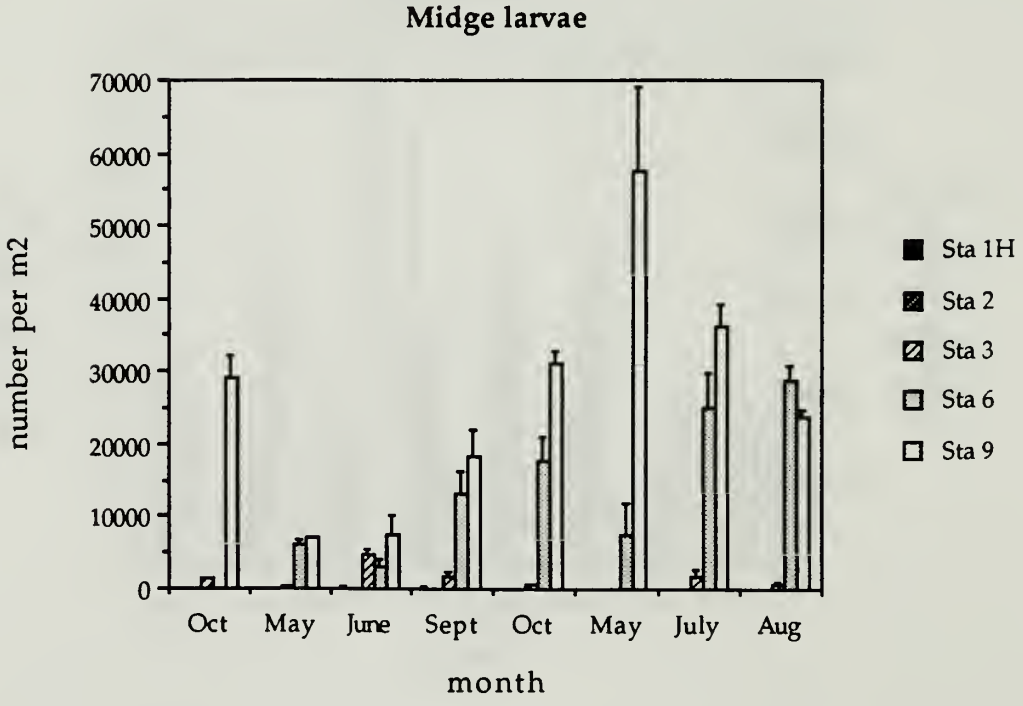


Fig. 38. Continued.

Station 3: Maximum abundances, while variable, were found in June 1991 at station 3 (averaging just over 100,000 m^{-2}; Fig. 36). Animal numbers were relatively high in May of 1991 (60,000 m^{-2}); however, the average value in May of 1992 was one of the lowest (under 25,000 m^{-2}). Although gastropods, an important member of the benthic community at this site, peaked in late summer and fall (September and October of 1991 and August of 1992; Fig. 38), the pattern for total macrofauna at station 3 was more a reflection of polychaete seasonality. The peak in June was primarily due to tremendous numbers of polychaetes (Fig. 38) which accounted for about two-thirds of total abundance at this time.

Station 6: No clear trend was seen for Station 6, where the number of animals was distinctly lower (averaging between 10,000 and 30,000 m^{-2}) than at the other four stations (Fig. 36). Slightly higher abundances were seen in July and August of the second summer (almost 30,000 m^{-2} for each date). Except for May of 1991 when amphipods briefly peaked, the seasonal pattern for station 6 was primarily explained by abundances of midge larvae (Fig. 38).

Station 9: At station 9, highest numbers were seen in May of 1992 (approximately 80,000 m^{-2}) although one of the lowest counts came in May of 1991 (just over 20,000 m^{-2}; Fig. 36). Changes in abundance of midge larvae accounted for much of the variation seen at this site, although oligochaetes contributed to the peak in May 1992, and amphipods were important in October 1990 and June 1991 (Fig. 38).

Macrofauna In Larger Cores

Similar species to those in the smaller cores were found in the larger cores as well (Table 30). The data have not been graphed because they are not quantitative; many of the animals could have and did pass through the 3 mm screen. There were only three benthic species that were not sampled by the smaller cores: *Glycera dibranchia*, *Heteromastus filiformis*, and *Macoma balthica*. Two of these are closely related to small core species (*H. filiformis*, *Capitella capitata*; *M. balthica*, *Tellina agilis*). In general, the size of animals sampled by the larger cores was greater than those sampled by the smaller cores so that in a few cases macrofauna could be more easily keyed to species (e.g. for *Nereis* and *Scoloplos*). *Scoloplos* was abundant in the large cores; most have not yet been keyed to species because identification is slow and tedious.

DISCUSSION

The species found in Bass Harbor Marsh are common members of the benthic community of an estuary. The benthic invertebrates found in the lower part of the Bass Harbor Marsh estuary are typical of the region. In a recent study of the

Table 30. Benthic macrofauna in large cores, 1991.

		Sta IH					Sta 2							
		16May	11 Sep	11 Sep	11 Sep	22 Oct	19 Jun	19 Jun	19 Jun	11 Sep	11 Sep	23 Oct	23 Oct	23 Oct
	Species	1,2,3	core 1	core 2	core 3	1,2,3	core 1	core 2	core 3	core 1	core 2	core 1	core 2	core 3
TURBELLARIA	Turbellarians													
OLIGOCHAETA	Oligochaetes	2		1	2		1							
POLYCHAETA	*Capitella capitata*													
	Glycera dibranchia						1						1	
	Heteromastus filiformis	2				1		1	1			2		2
	Nereis virens	2			2	1	1			1		1	3	
	Polydora ligni						4	2	2					
	Scoloplos sp.	19	1		8		5	17	10	4		20	3	7
	Streblospio benedicti													
	Tharyx acutus						1							
	Unknown Polychaete			1										
BIVALVIA	*Gemma gemma*										1			
	Macoma balthica	1	1						1					
	Mya arenaria										1			
GASTROPODA	*Hydrobia minuta*													
AMPHIPODA	*Gammarus tigrinus*													
DECAPODA	*Crangon septemspinosa*			1		3	3			1				
INSECTA	Chironomidae larvae													
	Chironomidae pupae													
	Unknown Insect													
OSTEICHTHYES	*Anguilla rostrata, elver*													
	Apeltes quadracus													
	.													
Sta 1H comments	May - 3 cores taken, all animals put in one jar (labelled 1M) / 6 representative gastropods were hand sampled (2 species of Littorina													
	shells were empty though)													
	June - too deep to take large cores (tide coming in quickly)													
	October - 3 cores taken, all animals in one jar; only station sampled on Oct. 22 (rest on Oct. 23)													
Sta 2 comments	May - too deep to sample with 6.5 in. diameter corer; took 4 samples with "scooper" sieve - no big animals so nothing saved													
	September - only 2 jars													
Sta 3 comments	May - 3 cores taken - no animals in core 1													
	June - 3 cores taken - not many animals, so put all in one jar													
	September - no jars													

Table 30 (continued).

		Sta 3				Sta 6				Sta 9		
		16 May	16 May	19 Jun	23 Oct	19 Jun	19 Jun	11 Sep	23 Oct	16 May	11 Sep	23 Oct
	Species	core 2	core 3	1,2,3	core 1	core 2	core 3	core 1	c's 1&3	c's 2&3	core 3	1,2,3
TURBELLARIA	Turbellarians			1								
OLIGOCHAETA	Oligochaetes									4	4	
POLYCHAETA	*Capitella capitata*			3								
	Glycera dibranchia											
	Heteromastus filiformis											
	Nereis virens											
	Polydora ligni		5	1								
	Scoloplos sp.	4	4	17								
	Streblospio benedicti		2									
	Tharyx acutus											
	Unknown Polychaete											
BIVALVIA	*Gemma gemma*											
	Macoma balthica											
	Mya arenaria											
GASTROPODA	*Hydrobia minuta*		17									
AMPHIPODA	*Gammarus tigrinus*									2		
DECAPODA	*Crangon septemspinosa*											
INSECTA	Chironomidae larvae	15	15	1	3	8	9	8	7			13
	Chironomidae pupae					1						
	Unknown Insect							1				
OSTEICHTHYES	*Anguilla rostrata, elver*					1						
	Apeltes quadracus			1								
Sta 6 comments	May - 3 cores taken; in 2 cores, midge larvae (as in Station 3) - not quantitative since they were small enough to											
	easily pass through screen, so not saved											
	June - 3 cores taken - no animals in core 1											
	September - 3 jars - no animals in 2 jars (after sieving in lab)											
	October - 3 cores taken - no animals in core 2; cores 1 & 3 combined											
Sta 9 comments	May - 3 cores taken - nothing in core 1; cores 2 & 3 combined											
	June - 3 cores taken - bottom very gravelly - no animals present											
	September - 3 jars - no animals in 2 jars (after sieving in lab)											
	October - 3 cores taken, all animals in 1 jar											

macrofauna at two mudflat communities on Mount Desert Island, many of the same species were dominant there, e.g. *Streblospio benedicti*, *Polydora ligni*, and *Hydrobia minuta* (Cammen and Larsen 1992). At station 3, characterized by extensive beds of green filamentaous macroalgae, large populations of *Hydrobia minuta* were observed. Mandracchia and Ruber (1990) found that snail densities (including the species *Hydrobia truncata*) were positively correlated with the presence of floating algal mats of the genus *Cladophora* in two Massachusetts salt marsh pools.

In freshwater systems, midge larvae, oligochaetes, and amphipods are commonly found (Lopez 1988). The upper Pamet River estuary on Cape Cod is distinguished by freshwater vegetation including *Potamogeton* spp. and water lilies, and the benthos is dominated by larval midges (family Chironomidae) and oligochaetes (72.5% and 16.8% of total organisms, respectively; Marine Research, Inc. 1986). This is very similar to the benthic community at station 9 (Table 29). Both midge larvae and oligochaetes are commonly found in areas of soft bottom in stagnant to slow-moving waters (Pennak 1978).

For more information on benthic macrofauna in Acadia National Park, see Greene et al. (1992) for a summary of historical work on invertebrates in this region.

Factors Affecting Composition Of Benthic Communities

There are two key environmental variables affecting benthic species composition, species richness, and animal abundances in this marsh-estuarine system: salinity regime and habitat type. In Bass Harbor Marsh, salinity may be more important.

Salinity

According to Lopez (1988), salinity is the major environmental factor restricting the distribution of marine and lacustrine taxa, while Kinne (1966) described salinity as the "ecological master factor" affecting distributional patterns of estuarine organisms. Even though Gray (1974) acknowledged the importance of salinity in restricting animal distribution, he stated that "most estuaries show just as dramatic changes in substrata as salinity changes and it remains to be seen which factor really limits distribution patterns for many brackish-water species." In Bass Harbor Marsh, salinity fluctuated greatly both tidally and seasonally as well as from year to year. First, salinity varied greatly between tides, as much as 15‰. Secondly, salinity varied widely between seasons; e.g. it was much lower in October 1991 than in June 1991. And finally salinity was lower in 1992 than in 1991. Although salinity would be expected to fluctuate less intensively in the substrate than in the overlying water (Kinne 1966), the large daily and seasonal changes would be stressful to benthic fauna.

The number of species vs. salinity in Bass Harbor Marsh (Fig. 34) is similar to Remane's well-known graph which shows a large decline in species richness in the brackish part (3-8‰) of the estuary (Remane 1934 in Remane and Schlieper 1971). There was no increase in species number at station 9, the "freshwater" endpoint, as might be expected. This is probably because saltwater occasionally reached this site. Most measurements of salinity fell between 0.01-0.10‰; however, salinity could be as high as 10‰ (as observed in September 1991).

Although station 9 was not strictly a freshwater site, the freshwater stream Marshall Brook which enters the marsh-estuarine system near station 9 was sampled at five sites for benthic invertebrates in the early fall of 1979 (Hansen 1980). Sampling methodology was different but similar taxonomic groups were present in Marshall Brook and at station 9 (e.g. Chironomidae larvae, Oligochaeta). Species richness was higher overall in Marshall Brook than at station 9 but this is partially because Insecta (with the exception of Diptera larvae) were not identified to order in this study as they were in the Marshall Brook study; they were simply classified as "Unknown Insecta" (although insects other than Diptera larvae were uncommon). Therefore it is not clear whether species richness is actually higher in the freshwater stream.

Species number declined from station 2 to station 1H although according to Remane's graph it would be expected to increase. One explanation worth investigating is sediment type. We did not take samples to characterize the sediment at each station but our recollection is that station 2 was muddier than station 1H. Species diversity and abundance are generally higher in muddy vs. sandy sediments (e.g. Heck et al. submitted) and thus a sandier substrate at station 1H might account for the lower species richness.

Submerged vegetation

One of the most notable features of seagrass beds such as *Zostera marina* (eelgrass), *Ruppia maritima*, and *Potamogeton* is that populations of small fish and benthic invertebrates tend to be more abundant and diverse in areas dominated by submerged vegetation compared to adjacent, unvegetated habitats (e.g. Williams and Thomas 1967, Orth 1973, Adams 1976a, 1976b, Orth 1977, Heck and Orth 1980, review by Orth et al. 1984). Submerged vegetation provides several benefits: (1) increased food supply; (2) refuge from predation; and (3) stability of the sediment for macroinvertebrates.

Abundant epifaunal communities including amphipods, isopods, gastropods, insect larvae, and grass shrimp occur in vegetated areas and feed on epiflora, plankton, and algal detritus associated with the vascular plant physical structure (e.g. Marsh 1973). Decay of the macrophytes *Ruppia* and *Potamogeton* also provides an important input of organic matter to the ecosystem in the fall

(Tenore 1972). Epifaunal and infaunal invertebrates are then in turn consumed by large numbers of small fish, which in the upper Chesapeake Bay were up to 10 times more numerous in plant communities, with peak fish abundances coinciding with peak plant biomass in July through September (Kemp et al. 1984).

The macroalgae found extensively at station 3, may provide some of the same advantages to fauna as the seagrasses discussed above. For example, snails associated with these algal mats in Massachusetts derived two benefits: they apparently ingested the epiphytic algae, bacteria, and detrital materials trapped in the *Cladophora* matrix; and *Cladophora* offered protection against predators which included the small fish *Fundulus heteroclitus* and shore birds (Mandracchia and Ruber 1990). One disadvantage was the loss of animals when tides and winds displaced *Cladophora* to nearby grassy areas.

Adversely, declines in oxygen may occur in dense macroalgal mats, with a resulting decline in abundance and number of species of fish and benthic invertebrates (Rosenberg 1985, Deegan et al. 1991). Heck et al. (1995) speculated that anoxic conditions could have been produced by large amounts of *Ruppia maritima* detritus and marsh peat at their marsh pool site, where abundance, biomass and secondary production of benthic macrofauna were unexpectedly low. In Bass Harbor Marsh, some evidence of oxygen stress at station 3 (Fig. 6b) was noted, although hypoxic conditions were not prolonged or widespread throughout the estuary.

Given this information, macroalgae at station 3, *Ruppia maritima* at station 6, and *Potamogeton* at station 9 should have provided a valuable habitat for benthic infauna. While macroalgae, *Ruppia*, and *Potamogeton* did influence the benthic species found, animal abundances and species richness were not higher at these stations as might have been expected. However, submerged plants have only been studied to a limited extent in brackish waters despite their widespread distribution in these habitats (*Ruppia*, e.g., can occur throughout the full salinity range) (Kemp et al. 1984); thus much more needs to be learned about the value of submerged vegetation as a habitat type in these waters.

Therefore, the stress of the salinity regime at the upper estuarine sites may have prevailed over the advantages of the submerged vegetation, resulting in decreased animal abundances (station 6) and species richness (stations 6 and 9) compared to the lower estuary (Figs. 33 and 34). Abundances of macrofauna were comparable at station 3 with those of station 2 (Fig. 33). However, the decline in species richness at station 3 (Fig. 34) again suggests that decreased salinity, while perhaps less stressful here than at the brackish/freshwater stations, may have been adversely affecting the bottom community.

Seasonal Patterns

Seasonal variations in species abundance reflect annual cycles of reproduction and mortality (e.g. Watling 1975, Holland et al. 1977, Whitlatch 1977). Typically, one might expect a spring peak due to recruitment and perhaps a second smaller peak in the fall as stresses (such as low oxygen and predation) lessen. However, there was no clear pattern for seasonality in Bass Harbor Marsh; trends were quite variable between stations. One of the problems with looking at seasonality of total macrofaunal abundances is that there are differences in breeding times of the various species co-existing at one site (discussed further under "Life History" in Appendix).

Fluctuations in benthic abundances were relatively modest compared to other soft bottom estuarine habitats in North America where fluctuations over several orders of magnitude are often reported (e.g. Holland et al. 1987). A common explanation is that areas dominated by opportunistic species such as *Streblospio benedicti* or *Capitella capitata* show large seasonal fluctuations while those dominated by longer-lived, less fecund species such as *Nephtys* sp. show smaller fluctuations (McCall 1977). Opportunistic characteristics include initial response to disturbed conditions, ability to increase rapidly, large population size, early maturation, and high mortality (Grassle and Grassle 1974). In Bass Harbor Marsh, opportunistic species such as *Capitella capitata*, *Streblospio benedicti*, *Polydora ligni*, and *Gemma gemma*, were dominant members of the benthos at the lower marsh sites but did not show great fluctuations in numbers.

Some of the factors affecting seasonal patterns in benthic communities are life histories of individual species, environmental variables and stresses, and predation. Each will be discussed briefly.

Life history

Many of the species in this estuary breed two or more times per year (e.g. *Streblospio benedicti*, *Gemma gemma*, *Gammarus tigrinus* - Bousfield 1973, Grassle and Grassle 1974, Thompson 1982) or even year-round (e.g. *Capitella capitata*, *Polydora ligni* - Grassle and Grassle 1974, Watling 1975, Warren 1976) and this would reduce expected seasonality in numbers. Watling (1975) noted that although numbers of *S. benedicti*, *C. capitata*, and *P. ligni* were greatest in the early summer in Rehoboth Bay, Delaware, these species also dominated during the winter months and thus should not be considered strictly summer species. This ability to breed several times per year may also result in different seasonal trends for the same species at different sites. For example, seasonal patterns of *Streblospio benedicti* abundance were very different at stations 1H, 2, and 3.

In some cases, a poor correlation in numbers was seen from May to May, and October to October, although species were similar from year to year for the most

part. Interannual variability in abundances from October to October over a three-year period also occurred in a nearby study, although again, dominant species were similar from year to year (Cammen and Larsen 1992). Even within a species, breeding time can vary. Nichols and Thompson (1985) found that although *Streblospio benedicti* and *Gemma gemma* abundances usually peaked during seasonal recruitment of juveniles to the population, they did not vary on a seasonally predictable basis from one year to the next. This apparently also occurred for these two species (as well as for others) in Bass Harbor Marsh.

Environment

In many estuarine areas, low oxygen is a water quality problem in the summer months (July and August), which can have a noticeable and adverse effect on the benthic community. However, in Bass Harbor Marsh the data did not indicate that hypoxia or anoxia was a problem and benthic abundances were not much lower at this time of the year, if at all.

Holland et al. (1987) concluded that seasonal changes in physico-chemical conditions had major effects on shifts in benthic macrofaunal abundance and species composition. This possibility has not yet been investigated but is worthy of strong consideration.

Predation

Disturbances by predators can greatly affect the seasonal cycles of benthic macrofauna (Nichols and Thompson 1985). Fish are probably important predators on benthic animals in Bass Harbor Marsh. Fish abundances in the total system were highest in September 1991 and August 1992 (although the high September values may be due in part to greater sampling effort) and so one might expect fish predation on benthic macrofauna to be greatest during these months. However, no clear relationship (inverse or otherwise) was found between fish and benthic invertebrate abundances. If seasonal abundances of fish and benthic macrofauna were compared by station, perhaps some type of correlation between the two faunal groups could be discerned.

Evidence Of Eutrophication

Although a limited increase in productivity in estuaries would not necessarily be harmful (Tenore 1972), increases in algal densities and production of larger amounts of detritus in the system can lead to oxygen deficiency at the bottom which is sometimes associated with the mortality of bottom fauna and demersal fish (Tenore 1972, Rosenberg 1985). Therefore besides providing a baseline inventory of benthic animals in the Marsh, we also hoped to answer a key

question: whether benthic macrofauna provided evidence of eutrophication in this system. Interpretation of our data suggests nutrient enrichment at some stations while also supporting the idea of salinity regime as a powerful force in shaping the benthic community in Bass Harbor Marsh.

Species abundance and richness

Although it is difficult to compare macrofaunal abundances with other studies because of differences in methodology (especially corers and sieves) used by various investigators, the abundances found at the five stations in this study do not suggest extremely high values and probably do not indicate a eutrophication problem. However, it is possible that benthic numbers were underestimated at least at station 3 by not sampling fauna living on the vegetation.

Species richness was relatively high in the lower estuary which would be characteristic of a non-enriched system. Although low species richness at stations 6 and 9 may be partially due to salinity stress, another possible explanation is that the small number of different taxa present is a reflection of eutrophication. This is supported by the relatively high water column nutrient values (especially compared to the lower estuary) as well as high macrophyte biomass at these two stations. This explanation was suggested for Marshall Brook where water quality was impacted by landfill leachate and benthic species diversity was low (Hansen 1980). On the other hand, the dominant group in the upper estuary, Chironomidae larvae, is not necessarily an indicator of enrichment; these larvae are opportunistic and may be present because of the highly variable salinity regime (discussed below).

While salinity stress was suggested for the decline in species number from station 2 to station 3, nutrient enrichment may also be a factor here as at stations 6 and 9. At station 3, macreoalgal biomass was high and episodes of low dissolved oxygen were recorded (see Fig. 6); factors suggesting enrichment. The underestimation of animal numbers (discussed above) and dominant species (discussed below) at station 3 also suggest an enriched site.

Species composition

Many of the dominant benthic species at the higher salinity stations are considered indicative of enriched conditions; these include oligochaetes, opportunistic polychaete species such as *Capitella capitata*, *Streblospio benedicti*, and *Polydora ligni*, and gastropods such as *Hydrobia*. This was especially compelling for station 3 where *Hydrobia minuta*, *S. benedicti*, and *C. capitata* were the dominant species (Table 29). Pearson and Rosenberg (1978) stated: "The common occurrence of certain ubiquitous species in organically enriched areas over a wide geographical range is a constant temptation to biologists to regard

them as species indicative of organically polluted sediments, and to a certain extent this must be true." However, these species are also commonly found in organically poor areas and the authors cautioned that "... any attempts to use their presence in a sample as indicative of enrichment or pollution of an area from which the sample was obtained must always be qualified by consideration of the the full species range present and the environmental conditions prevailing at the time of sampling." Pearson and Rosenberg (1978) believed that it is important to look at changes in community structure rather than indicator species alone.

Many of the benthic species in this system are opportunistic; they include: polychaetes *Capitella capitata*, *Streblospio benedicti*, and *Polydora ligni* (stations 1, 2 and 3); the bivalve *Gemma gemma* (station 2); and Chironomidae larvae (stations 6 and 9). Characteristics of opportunistic species include several or all of the following: high fecundity, brooding of young, multiple generations per year, rapid growth, large population size, high mortality, ease of dispersion, ability to switch feeding modes, and tolerance to widely varying conditions. It is possible that opportunistic benthic species are present in Bass Harbor Marsh not so much because this system may or may not be enriched but because these species are well-adapted for survival in harsh environments, in this case a highly variable salinity regime which few species can tolerate. The benthos of the Pamlico River estuary in North Carolina is a physically controlled community composed of opportunistic species (e.g. *Mulinia lateralis* and *Heteromastus filiformis*) well-adapted for survival in harsh environments (Tenore 1972). These species have high reproductive rates and broad niches that allow the populations to survive, exploit, and dominate under rigorous environmental conditions.

CONCLUSIONS

In general, there appeared to be a healthy benthic community throughout Bass Harbor Marsh. Salinity and submerged vegetation were both important factors influencing benthic species composition, species richness, and animal abundances in this marsh-estuarine system although salinity may have prevailed at the upper estuarine sites. Expected seasonality of total macrofauna may have been dampened because of the differences in breeding times of the various species co-existing at one site, the ability of many species to breed for an extended part of the year, and the apparent absence of stresses such as hypoxia or anoxia in the summer. Although early colonizing and/or opportunistic species that are often indicative of enrichment dominated most sites within the system, our results do not necessarily indicate enriched conditions because animal abundances were moderate in most cases, species richness was relatively high at least in the lower estuary, and the presence of these species may have been more a reflection of the highly variable salinity regime in Bass Harbor Marsh. However, there was possible evidence of enrichment particularly at

stations 3, 6, and 9, and the benthic community should be carefully monitored along with other chemical and biotic parameters in the future.

CONCLUSIONS

Habitat Characteristics

1) During the growing season, from May through October, the lower basin of Bass Harbor Marsh experiences episodes of dense macroalgal biomass dominated by filamentous green forms (e.g. *Enteromorpha, Cladophora, Rhizoclonium).* Although the floating marcoalgal mats appear quite dense, the biomass (peak = 171 g dry weight/m^2) was not excessive, especially when compared to other more nutrient-rich sites worldwide. The macroalgal data, along with biomass estimates of the submerged aquatic angiosperms, widgeon grass (*Ruppia maritima*) and pondweed (*Potamogeton*), serve as the only baseline to evaluate the future status of aquatic vegetation in the estuary. Excessive macroalgal growth is often a response to nutrient enrichment in shallow estuaries.

2) Twenty-three (23) species of fish were collected from the Bass Harbor Marsh estuary representing a faunal composition and dominance pattern similar to other shallow estuaries in Maine, and elsewhere in New England. Common mummichog (*Fundulus heteroclitus*), fourspine stickleback (*Apeltes quadracus*), and Atlantic silverside (*Menidia menidia*) were the dominant species collected in the saline and brackishwater portions of the estuary. At the freshwater end, brook trout (*Salvelinus fontinalis*) and golden shiner (*Notemigonus crysoleucas*), among others, were collected. Commercially important species, such as Atlantic herring (*Clupea harengus*) also utilize the Bass Harbor Marsh estuary. Portions of the marsh dominated by widgeon grass had high fish abundance, while abundance was lower in dense macroalgal-dominated habitats.

3) Salinity and habitat (i.e., macroalgae, submerged aquatic vegetation, mud) appear to be the most important factors affecting the distribution, species richness, and abundance of benthic species throughout the Bass Harbor Marsh estuary. Number of species in relation to salinity appeared to follow the classic relationship with low species richness in brackish areas (3-8 ppt salinity) and higher richness toward both the freshwater and marine ends of the estuary. Opportunistic species that often indicate nutrient enriched conditions were found in Bass Harbor Marsh; however, because abundances were moderate and the salinity regime was so variable in the estuary, it cannot be stated that these species, in fact, are indicative of enriched conditions in this system.

Water Quality

4) Five freshwater brooks drain into the Bass Harbor Marsh estuary (Adams, Buttermilk, Lurvey/Heath, Marshall, and un-named brook from China Hill). A landfill is associated with the Marshall Brook drainage basin. Marshall Brook

exhibited the highest concentrations of nitrate+nitrite (range 6-21 *u*mole/l) compared to the other brooks (0-6 *u*mole/l). Marshall Brook was also the dominant freshwater source (i.e., loading) of nitrate+nitrite to the estuary.

5) Nutrient inputs to the marsh from the freshwater sources and the ocean were compared. Of the total of the two sources, 52% of the dissolved inorganic nitrogen (ammonia, nitrate+nitrite) was from the freshwater sources and 48% from the ocean. For dissolved inorganic phosphorus (phosphate), 95% came from the ocean source, as would be expected.

6) The ratio of nitrogen to phosphorus is often used to indicate which nutrients will most likely limit primary productivity in an estuary. Phytoplankton, macroalgae, and aquatic plants require an N:P ratio of near 16:1 for optimal growth. In Bass Harbor Marsh the 16:1 ratio occurred in the lower basin, and as expected, macroalgae biomass was high. Further upstream, where widgeon grass and pondweed dominated, the N:P ratio was greater than 16:1 suggesting P limitation. This area was not conductive to the free-floating macroalgae, whereas the rooted aquatics could sequester needed P from the sediment.

7) As predicted by steady state box modeling, if dissolved inorganic nitrogen loading from Marshall Brook were decreased to levels equivalent to the other freshwater brooks entering the marsh-estuary, the area of 16N:1P ratio waters would dramatically shift upstream. Given this scenario it is suggested that the macroalgae biomass in the lower basin would not be as prolific as currently observed. If oceanic input of dissolved inorganic nitrogen were increased by 50% (perhaps simulating a dramatic increase in development around the shores of Bass Harbor), there would probably be little influence on the distribution of nutrients in the marsh.

Long-term Monitoring

8) Long-term monitoring of the water quality and ecological characteristics of Bass Harbor Marsh should be pursued. The data presented in this report are the only comprehensive baseline for the system (aside from water quality monitoring from the Worcester Landfill site) so statements regarding trends in the habitat quality or water quality cannot be made with any certainty. Having made this cautionary note, our data do show some indications that the Bass Harbor Marsh may be tending toward eutrophied (i.e., nutrient-rich) conditions -- relatively dense zones of macroalgae occur; fish communities are typical of other New England systems, yet abundance is low in macroalgae areas; benthic species which are indicative of nutrient-rich conditions occur in the marsh, albeit at low abundances; and, nitrogen loading from the Marshall Brook freshwater sources is particularly high. These observations justify the need to implement a monitoring program to determine trends in the system. Is macroalgal biomass increasing in the estuary, as anecdotal reports suggest? Are the species composition,

abundance and relative distribution of fish and benthic communities changing? Are the concentrations of nitrogen and phosphorus in the estuary relatively stable from year-to-year, increasing, or decreasing? What are the trends in nutrient loading to the estuary from the ocean and freshwater sources?

A long-term monitoring program should include periodic evaluations of nutrient distributions within the estuary. Should trends of increased nutrient concentrations be noted, then monitoring of nutrient loading should be initiated. Less frequent assessments of macroalgae, fish and benthic communities are needed. Protocols for the monitoring program must be documented when knowledge of available funds and personnel are known. However, the following minimum requirements are recommended.

Nutrient Distributions -- As noted in this report, the area of 16N:1P is critical to the distribution and growth of macroalgae in the system. Nutrient concentrations should be collected at least three times per year (Apr-May, Jul-Aug, Nov-Dec) in similar fashion as in this study from a minimum of the following stations (1, 3, 6, 9). Should nutrient concentrations increase significantly from our baseline study or the monitoring data set, then monitoring of nutrient loading should also be considered in an effort to identify the source.

Macroalgae, Fish, Benthos -- Sampling, sorting and analyzing ecological data sets is very time consuming. We recommend that macroalgae, fish and benthos be monitored (following the methods used herein) at 5-7 year intervals. However, should water quality be observed to degrade, then more frequent monitoring is recommended.

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APPENDICES

Water Quality and Discharge from Freshwater Brooks A3
Key: FWI = Freshwater Input ($m^3 s^{-1}$)
All nutrient concentrations are in *u*moles/l, except for DOC (mg/l)

Water Quality for Marsh-Estuary A5
Key: DEP = Depth (m)
SAL = Salinity (ppt)
TID = Tide Stage, HT = high slack water, LT = low slack water
All nutrient concentrations are in *u*moles/l. DOC and Chl a are in mg/l.

Water Quality at Station 1 (Rt 102 bridge) A25
Key: Same as above appendix, except EB = ebb tide and FL = Flood tide

Life History of Dominant Benthic Macroinvertebrates A31

BASS HARRBOR MARSH
WATER QUALITY AND DISCHARGE DATA FOR FRESHWATER BROOKS

DATE=42292

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
Adm	0.145	.	0.32	0.00	47.82	0.33	0.00	11.68	25.28	0.18
Bmk	0.096	.	2.10	0.00	29.64	1.78	0.00	8.60	23.73	0.28
Chn	0.097	.	0.71	1.42	23.95	2.67	0.00	7.01	19.18	2.92
L+H	0.153	.	1.84	0.00	34.95	3.10	0.00	6.41	18.05	0.20
Mar	0.232	.	15.76	0.00	41.75	9.02	0.06	4.14	39.41	0.22

DATE=51491

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
Adm	0.07	.	0.00	0.00	16.05	2.60	0.00	16.9230	36.31	0.41
Bmk	0.03	.	0.00	0.01	.	0.68	0.00	11.2233	27.46	0.41
Chn	0.02	.	0.00	0.00	.	0.70	0.00	8.8605	21.69	0.40
L+H	0.04	.	1.95	0.00	14.18	0.56	0.00	6.3410	23.06	0.43
Lur	.	.	0.00	0.00	.	0.39	0.00	.	.	.
Mah	.	.	8.18	0.00	22.94	3.87	0.02	.	.	.
Mar	0.07	.	6.12	0.00	6.34	0.45	0.01	4.7808	19.78	0.27

DATE=61791

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
Adm	0.527	9.85	5.23	0.15	51.84	2.16	0	13.3157	39.35	0.63
Bmk	0.165	0.36	1.78	0.00	109.15	1.15	0	19.7008	38.55	0.50
Chn	0.140	0.04	0.70	0.00	28.71	0.05	0	17.5215	35.31	0.43
L+H	0.184	0.04	6.42	0.01	124.89	3.04	0	14.5329	41.26	0.56
Mar	0.257	0.05	7.50	0.05	88.15	1.61	0	11.7767	37.55	0.48

DATE=72192

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
dm	0.127	.	0.00	0	49.82	0.97	0.00	32.18	50.39	0.42
mk	0.086	.	0.00	0	96.48	0.31	0.00	23.20	42.93	0.37
hn	0.073	.	0.00	0	91.04	0.31	0.00	19.68	42.77	1.35
+H	0.113	.	0.21	0	81.76	0.37	0.00	16.08	37.74	0.43
ar	0.266	.	18.74	0	92.44	0.21	0.03	11.97	50.33	0.36

DATE=90991

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
Adm	0.000	.	0.00	0.00	69.37	2.33	0.00	51.6636	81.47	0.59
Bmk	0.003	.	0.00	0.00	94.55	5.13	0.00	28.1580	.	0.80
Chn	0.006	.	0.00	0.00	117.46	0.43	0.00	17.8321	37.85	0.58
L+H	0.016	.	4.38	0.00	138.71	0.28	0.03	11.3036	36.16	0.53
Mar	0.015	.	9.55	0.03	131.85	0.31	0.09	6.0192	26.59	0.27

BASS HARRBOR MARSH
WATER QUALITY AND DISCHARGE DATA FOR FRESHWATER BROOKS

---------- DATE=102291 ----------

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
Adm	0.315	.	0.00	0.00	81.80	1.97	0	32.6587	51.25	0.39
Bmk	0.138	.	0.00	0.00	117.47	0.51	0	22.6279	35.70	0.45
Chn	0.179	.	0.00	0.00	116.35	0.44	0	17.5355	25.32	0.24
L+H	0.246	.	0.00	0.09	107.04	0.34	0	13.6240	23.78	1.00
Mar	0.218	.	8.88	0.00	121.20	0.23	0	9.8068	29.96	0.24

---------- DATE=112990 ----------

STA	FWI	PH	NO2_NO3	PO4	SIO2	NH3	NO2	DOC	TN	TP
Adm	0.10	3.1	0.40	0.01	97.46	0.83	0.00	22.230	.	.
Bmk	0.05	5.0	1.65	0.63	129.12	1.12	0.00	14.230	.	.
Chn	0.06	4.2	0.00	0.03	124.77	0.20	0.00	11.695	.	.
L+H	0.11	5.1	3.84	0.02	110.92	0.29	0.00	9.175	.	.
Mar	0.12	6.4	21.01	0.02	125.95	0.06	0.07	5.970	.	.

WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=42292

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
4:17	HT	1	.	26.925	1.28	0.96	13.27	0.12	0.19
3:58	HT	2	0.25	28.233	2.14	0.32	10.91	0.06	0.11
4:05	HT	3	0.10	2.575	3.38	0.00	50.74	0.53	0.02
4:05	HT	3	0.50	25.243	1.62	0.12	14.64	0.90	0.14
4:13	HT	4	0.10	2.312	4.88	0.00	56.10	3.78	0.00
4:13	HT	4	0.75	26.631	1.56	0.17	13.33	0.11	0.20
4:28	HT	5	0.20	9.988	4.89	0.00	37.48	3.21	0.00
4:38	HT	6	0.25	0.332	7.34	0.00	76.12	2.57	0.02
4:45	HT	7	0.25	0.141	7.49	0.81	31.38	2.26	0.00
4:55	HT	8	0.25	0.031	7.92	0.00	22.68	4.24	0.00
5:10	HT	9	0.25	0.022	9.11	0.00	12.79	3.50	0.00
3:40	HT	A1	0.25	1.197	1.04	0.00	38.40	1.86	0.14
3:45	HT	A2	0.10	3.653	2.01	0.00	41.39	0.53	0.00
3:45	HT	A2	0.50	26.183	0.88	0.18	13.97	0.51	0.20
16:33	HT2	1	.	21.030	1.81	0.11	23.54	0.05	0.10
14:15	LT	1	.	2.347	4.40	0.00	53.46	2.86	0.00
14:06	LT	2	0.25	1.054	6.01	0.00	41.51	3.27	0.01
14:06	LT	2	0.50	21.414	1.63	0.36	17.43	2.82	0.07
14:21	LT	3	0.15	1.019	3.32	0.00	70.16	2.29	0.00
14:13	LT	4	0.10	0.932	5.91	0.00	39.67	2.53	0.01
14:13	LT	4	0.50	23.018	0.87	0.25	11.63	2.34	0.36
14:32	LT	5	0.15	0.189	7.19	0.00	36.43	1.38	0.01
14:42	LT	6	0.25	0.163	7.57	0.00	29.16	3.27	0.03
14:48	LT	7	0.25	0.099	7.67	0.00	39.85	2.63	0.05
14:56	LT	8	0.25	0.017	7.61	0.00	35.74	1.56	0.02
15:09	LT	9	0.25	0.014	7.23	0.00	29.53	3.49	0.02
13:44	LT	A1	0.15	0.165	0.00	0.78	49.22	0.21	0.00
13:51	LT	A2	0.10	1.721	0.52	0.00	41.78	2.49	0.00

WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=51591

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
13:30	HT	1	.	29.06	0.00	0.19	6.61	1.34	0.00
13:25	HT	2	0.25	29.22	0.00	0.20	4.51	0.32	0.00
13:53	HT	3	0.25	28.35	0.00	0.54	5.24	0.04	0.01
14:00	HT	4	0.25	28.97	0.00	1.23	4.55	0.92	0.00
14:11	HT	5	0.25	21.00	0.23	0.01	18.92	1.02	0.00
14:20	HT	6	0.25	9.76	1.22	0.00	39.27	2.33	0.00
14:20	HT	6	1.00	23.01	0.06	0.02	8.63	0.12	0.01
14:30	HT	7	0.25	5.38	1.87	0.00	53.91	3.00	0.00
14:30	HT	7	1.00	20.84	0.16	0.01	10.78	1.10	0.00
14:42	HT	8	0.25	1.58	2.59	0.00	71.29	0.30	0.00
14:42	HT	8	1.50	22.46	0.13	0.01	8.31	1.19	0.02
14:58	HT	9	0.25	0.28	1.71	0.02	73.15	1.08	0.00
13:40	HT	A1	0.25	26.23	0.00	0.00	6.18	0.12	0.00
13:45	HT	A2	0.25	25.63	0.00	0.02	7.85	0.27	0.00
10:15	LT	1	.	27.61	0.00	0.03	6.34	0.97	0.01
10:15	LT	2	0.50	29.46	0.00	0.16	3.44	0.11	0.01
10:36	LT	3	0.20	29.38	0.00	0.11	3.40	0.53	0.01
10:25	LT	4	0.12	17.00	0.50	0.00	24.28	1.30	0.00
10:25	LT	4	0.50	30.01	0.00	0.19	3.09	1.32	0.03
10:45	LT	5	0.12	8.65	1.38	0.00	44.37	2.30	0.00
11:00	LT	6	0.12	2.38	2.57	0.00	61.41	2.26	0.00
11:00	LT	6	0.75	21.26	0.15	0.00	11.26	2.48	0.00
11:10	LT	7	0.40	15.51	0.56	0.00	21.18	1.49	0.00
11:23	LT	8	0.10	0.89	3.19	0.00	69.49	1.73	0.00
11:23	LT	8	1.00	22.46	0.13	0.01	9.01	2.31	0.01
11:36	LT	9	0.32	0.47	2.99	0.01	74.15	0.63	0.00
10:00	LT	A1	0.20	9.74	0.70	0.00	17.19	0.83	0.00
10:07	LT	A2	0.12	24.47	0.00	0.08	6.89	0.14	0.00
22:00	LT2	1	.	23.67	0.00	0.08	10.47	0.21	0.00

DATE=61891

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
5:30	HT	1	.	30.40	0.00	0.24	3.80	0.50	0.00
5:20	HT	2	0.50	30.47	0.58	0.33	3.74	4.90	0.04
5:50	HT	3	0.00	22.89	0.00	0.00	14.69	0.13	0.00
5:50	HT	3	0.50	28.27	0.00	0.12	4.96	0.00	0.00
5:55	HT	4	0.50	30.01	0.00	0.22	5.49	1.72	0.00
6:10	HT	5	0.25	13.92	0.40	0.00	42.23	0.77	0.00
6:25	HT	6	0.25	5.11	4.62	0.00	77.02	1.57	0.00
6:25	HT	6	1.00	0.66	1.44	0.00	54.95	1.51	0.00
6:30	HT	7	0.00	2.52	9.31	0.00	84.27	2.26	0.00
6:40	HT	8	0.25	0.52	13.97	0.00	101.33	10.72	0.00
6:40	HT	8	1.50	17.67	0.46	0.00	17.86	5.52	0.00
6:58	HT	9	0.25	0.06	15.63	0.00	108.79	2.98	0.00
5:40	HT	A1	0.25	14.78	0.00	0.00	19.67	0.30	0.00
5:30	HT	A2	0.00	20.86	0.00	0.00	18.30	0.29	0.00
5:30	HT	A2	0.50	28.81	0.00	0.14	6.94	0.13	0.00
14:52	LT	1	.	17.89	0.00	0.00	26.22	0.07	0.00
14:05	LT	2	0.00	13.47	0.90	0.01	38.82	0.99	0.00
14:05	LT	2	0.50	17.71	0.00	0.00	22.42	0.32	0.00
14:40	LT	3	0.00	16.47	0.00	0.00	25.93	0.70	0.00
14:44	LT	4	0.00	9.46	1.79	0.01	57.44	1.02	0.00
14:44	LT	4	0.50	19.04	0.82	0.02	27.17	0.60	0.00
14:57	LT	5	0.00	2.86	7.34	0.02	81.54	1.05	0.00
15:05	LT	6	0.00	0.79	13.01	0.04	95.57	2.60	0.00
15:05	LT	6	0.50	10.23	1.34	0.01	52.53	1.49	0.00
15:15	LT	7	0.25	0.35	13.54	0.02	100.37	2.78	0.00
15:15	LT	7	1.00	21.77	0.16	0.00	9.74	5.21	0.03
15:30	LT	8	0.00	0.21	12.68	0.00	102.90	6.46	0.00
15:30	LT	8	1.00	17.54	0.46	0.00	17.31	5.34	0.04
15:40	LT	9	0.25	0.10	12.79	0.00	110.98	2.14	0.01
14:25	LT	A1	0.25	4.63	0.00	0.06	34.65	2.69	0.00
14:17	LT	A2	0.12	19.20	0.00	0.03	10.23	0.27	0.00

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=72192

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
4:55	HT	1	.	25.987	0.05	0.22	12.77	0.30	0.05
4:42	HT	2	0.10	26.372	0.00	0.19	11.92	0.22	0.05
5:01	HT	3	0.10	4.993	0.00	0.00	49.84	0.00	0.00
5:01	HT	3	0.25	5.463	0.00	0.12	48.62	0.00	0.00
4:52	HT	4	0.10	5.495	0.00	0.00	49.28	0.32	0.00
4:52	HT	4	0.50	23.428	0.00	0.33	16.81	1.40	0.00
5:14	HT	5	0.10	0.277	0.00	0.00	57.86	0.23	0.00
5:25	HT	6	0.25	0.053	0.52	0.00	73.08	0.91	0.00
5:35	HT	7	0.25	0.033	1.18	0.00	74.88	0.21	0.00
5:45	HT	8	0.25	0.023	1.05	0.00	25.95	0.13	0.00
6:00	HT	9	0.25	0.022	2.04	0.00	87.80	0.48	0.00
4:25	HT	A1	0.10	0.735	0.00	0.00	53.76	0.18	0.00
4:34	HT	A2	0.10	5.463	0.00	0.00	.	0.59	0.14
4:34	HT	A2	0.25	21.590	0.05	0.33	20.77	0.49	0.12
17:23	HT2	1	.	28.373	0.00	0.23	7.96	0.52	0.00
14:00	LT	1	.	7.960	0.00	0.00	39.97	1.93	0.00
14:07	LT	2	0.10	2.894	0.00	0.00	54.36	0.71	0.00
14:23	LT	3	0.10	6.651	0.00	0.00	47.92	0.01	0.00
14:16	LT	4	0.10	2.377	0.00	0.00	55.20	0.09	0.00
14:16	LT	4	0.45	25.208	0.00	0.00	15.12	0.52	0.00
16:48	LT	5	0.10	0.105	0.00	0.00	68.04	0.13	0.00
15:00	LT	6	0.10	0.041	0.50	0.00	108.00	0.20	0.00
15:08	LT	7	0.10	0.038	0.62	0.00	108.48	0.31	0.00
15:18	LT	8	0.10	0.025	0.00	0.00	82.76	0.56	0.00
15:30	LT	9	0.10	0.041	1.68	0.00	89.64	0.27	0.00
13:47	LT	A1	0.10	0.305	0.00	0.00	52.82	0.18	0.00
13:58	LT	A2	0.10	5.052	0.00	0.00	41.33	0.01	0.00

WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=91091

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
14:20	HT	1	.	31.87	0.00	0.32	6.85	0.05	0.00
14:36	HT	2	0.25	31.76	0.00	0.58	6.78	0.00	0.00
14:09	HT	3	0.25	31.65	0.00	0.39	7.13	0.00	0.00
14:07	HT	4	0.25	31.64	0.00	0.34	6.74	0.00	0.00
13:56	HT	5	0.25	29.44	0.00	0.09	3.70	0.00	0.01
13:44	HT	6	0.25	25.18	0.00	0.00	1.37	0.00	0.00
13:37	HT	7	0.75	20.56	0.00	0.00	2.58	0.94	0.00
13:30	HT	8	0.25	16.68	0.00	0.00	10.06	0.06	0.00
13:23	HT	9	0.10	5.37	1.00	0.05	69.46	0.18	0.00
14:23	HT	A1	0.25	29.72	0.00	0.04	3.89	0.02	0.01
14:17	HT	A2	0.25	30.68	0.00	0.22	4.81	0.06	0.00
10:30	LT	1	.	30.27	0.00	0.05	5.38	0.06	0.04
10:28	LT	2	0.25	29.23	0.00	0.02	3.92	0.06	0.02
10:47	LT	3	0.10	29.83	0.02	0.05	2.93	0.75	0.02
10:39	LT	4	0.50	27.74	0.00	0.00	2.60	2.89	0.03
10:57	LT	5	0.10	21.24	0.00	0.00	2.82	0.18	0.00
11:08	LT	6	0.50	25.84	0.00	0.00	2.13	0.09	0.00
11:20	LT	7	0.10	9.35	0.54	0.00	38.83	0.42	0.00
11:20	LT	7	0.25	21.49	0.00	0.00	1.55	0.34	0.00
11:28	LT	8	0.10	6.45	0.83	0.02	56.74	0.43	0.00
11:28	LT	8	1.25	18.09	0.00	0.00	6.38	0.63	0.00
11:46	LT	9	0.10	0.68	6.18	0.01	127.39	0.79	0.00
11:46	LT	9	0.50	9.86	0.00	0.01	35.26	0.33	0.00
10:14	LT	A1	0.10	20.49	0.00	0.00	2.15	0.16	0.00
10:20	LT	A2	0.10	26.42	0.00	0.00	1.74	0.22	0.00

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=102291

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
12:00	HT	1	.	26.15	0.00	0.30	22.61	0.09	0.00
11:48	HT	2	0.25	26.63	1.91	0.44	21.28	0.42	0.09
12:13	HT	3	0.25	15.22	0.00	0.05	48.03	0.13	0.00
12:18	HT	4	0.25	20.89	0.02	0.17	34.84	0.09	0.00
12:28	HT	5	0.25	1.95	0.36	0.00	86.18	0.21	0.00
12:37	HT	6	0.25	0.05	0.58	0.00	95.31	0.29	0.00
12:43	HT	7	0.25	0.03	0.00	0.00	105.18	0.33	0.00
12:52	HT	8	0.25	0.02	0.00	0.23	109.93	0.32	0.00
13:05	HT	9	0.25	0.02	2.44	0.00	116.73	0.32	0.00
12:04	HT	A1	0.25	1.88	0.00	0.00	82.91	0.32	0.00
11:56	HT	A2	0.25	4.08	0.00	0.00	75.14	0.44	0.00
8:15	LT	1	.	2.74	0.88	0.00	83.19	0.25	0.00
7:54	LT	2	0.25	1.23	1.45	0.01	87.27	0.38	0.00
7:40	LT	3	0.12	4.45	0.00	0.00	76.52	0.19	0.00
7:33	LT	4	0.25	0.41	2.56	0.00	93.71	0.30	0.00
7:33	LT	4	0.60	22.38	2.24	0.02	30.43	2.01	0.11
7:20	LT	5	0.25	0.05	3.23	0.00	103.51	1.03	0.00
7:06	LT	6	0.25	0.06	3.83	0.03	109.65	0.50	0.00
7:00	LT	7	0.25	0.04	3.84	0.01	110.58	0.43	0.00
6:47	LT	8	0.25	0.03	4.01	0.01	115.42	0.33	0.00
6:36	LT	9	0.25	0.02	1.82	0.00	115.61	0.58	0.00
8:10	LT	A1	0.10	0.61	0.00	0.00	83.81	0.72	0.00
8:03	LT	A2	0.10	2.94	0.00	0.00	77.09	0.56	0.00

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=112890

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2
7:50	HT	1	.	28.00	7.67	0.69	26.52	0.56	0.25
8:37	HT	2	0.10	29.12	8.04	0.79	24.38	0.74	0.37
8:37	HT	2	0.50	29.51	8.07	0.84	23.04	0.14	0.33
17:07	HT	2	0.10	2.73	9.33	0.02	95.17	0.67	0.01
8:52	HT	3	0.10	1.63	5.06	0.06	96.23	1.65	0.00
8:52	HT	3	0.25	25.50	5.65	0.08	30.21	0.05	0.00
8:45	HT	4	0.10	2.41	5.70	0.06	92.47	2.38	0.00
8:45	HT	4	0.50	28.04	7.79	0.69	25.92	0.28	0.36
9:07	HT	5	0.10	0.70	5.30	0.01	104.91	2.03	0.00
9:17	HT	6	0.10	0.05	9.14	0.03	115.67	0.47	0.00
9:24	HT	7	0.10	0.05	7.43	0.32	117.60	0.36	0.00
9:33	HT	8	0.10	0.04	7.93	0.05	118.15	0.78	0.00
9:42	HT	9	0.10	0.04	11.30	0.02	120.97	0.83	0.00
8:25	HT	A1	0.10	0.57	1.00	0.00	86.53	1.20	0.00
8:30	HT	A2	0.10	0.31	3.95	0.00	93.90	0.95	0.00
17:00	LT	1	.	4.59	5.71	0.00	87.22	0.84	0.00
5:35	LT	2	0.10	18.77	7.23	0.24	52.85	0.49	0.00
5:45	LT	3	0.10	1.36	2.94	0.03	88.19	0.71	0.00
5:55	LT	4	0.25	1.22	6.17	0.00	98.56	0.97	0.00
5:55	LT	4	0.50	12.51	5.80	0.05	65.23	5.35	0.08
6:05	LT	5	0.10	0.06	7.04	0.00	114.35	1.42	0.00
6:17	LT	6	0.10	0.04	7.80	0.00	117.77	0.86	0.00
6:25	LT	7	0.50	0.04	9.09	0.02	116.83	1.51	0.00
6:33	LT	8	0.50	0.04	8.19	0.01	114.59	0.37	0.00
6:47	LT	9	0.10	0.04	8.26	0.05	120.05	1.10	0.00
5:15	LT	A1	0.10	0.43	1.28	0.00	91.73	1.25	0.00
5:22	LT	A2	0.10	0.15	0.12	0.01	93.81	0.71	0.00

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=42292

TIME	TID	STA	DEP	SAL	DOC	CHLA
4:17	HT	1	.	26.925	2.46	0.14
3:58	HT	2	0.25	28.233	2.25	0.07
4:05	HT	3	0.10	2.575	8.27	0.55
4:05	HT	3	0.50	25.243	2.51	0.35
4:13	HT	4	0.10	2.312	6.81	0.27
4:13	HT	4	0.75	26.631	2.12	0.09
4:28	HT	5	0.20	9.988	6.91	0.57
4:38	HT	6	0.25	0.332	5.88	0.25
4:45	HT	7	0.25	0.141	6.02	0.11
4:55	HT	8	0.25	0.031	6.41	0.17
5:10	HT	9	0.25	0.022	5.13	0.11
3:40	HT	A1	0.25	1.197	11.49	0.88
3:45	HT	A2	0.10	3.653	9.52	0.43
3:45	HT	A2	0.50	26.183	2.46	0.10
16:33	HT2	1	.	21.030	4.48	0.33
14:15	LT	1	.	2.347	7.73	0.25
14:06	LT	2	0.25	1.054	6.41	0.32
14:06	LT	2	0.50	21.414	4.36	0.40
14:21	LT	3	0.15	1.019	8.36	0.27
14:13	LT	4	0.10	0.932	6.63	0.55
14:13	LT	4	0.50	23.018	2.87	5.57
14:32	LT	5	0.15	0.189	5.96	0.39
14:42	LT	6	0.25	0.163	6.14	0.69
14:48	LT	7	0.25	0.099	6.45	0.21
14:56	LT	8	0.25	0.017	6.54	0.20
15:09	LT	9	0.25	0.014	8.51	0.20
13:44	LT	A1	0.15	0.165	12.52	0.78
13:51	LT	A2	0.10	1.721	11.87	0.39

DATE=51591

TIME	TID	STA	DEP	SAL	DOC	CHLA
13:30	HT	1	.	29.06	2.32	0.04
13:25	HT	2	0.25	29.22	2.63	0.05
13:53	HT	3	0.25	28.35	2.54	0.05
14:00	HT	4	0.25	28.97	2.50	0.03
14:11	HT	5	0.25	21.00	5.41	0.18
14:20	HT	6	0.25	9.76	7.20	0.67
14:20	HT	6	1.00	23.01	3.22	1.61
14:30	HT	7	0.25	5.38	8.98	0.59
14:30	HT	7	1.00	20.84	4.62	1.25
14:42	HT	8	0.25	1.58	6.44	0.35
14:42	HT	8	1.50	22.46	3.64	1.45
14:58	HT	9	0.25	0.28	6.74	0.12
13:40	HT	A1	0.25	26.23	3.69	0.13
13:45	HT	A2	0.25	25.63	4.00	0.10
10:15	LT	1	.	27.61	4.61	.
10:15	LT	2	0.50	29.46	2.28	0.13
10:36	LT	3	0.20	29.38	2.32	1.13
10:25	LT	4	0.12	17.00	5.74	0.39
10:25	LT	4	0.50	30.01	1.87	0.19
10:45	LT	5	0.12	8.65	6.70	0.59
11:00	LT	6	0.12	2.38	6.66	0.47
11:00	LT	6	0.75	21.26	3.84	0.76
11:10	LT	7	0.40	15.51	5.90	0.56
11:23	LT	8	0.10	0.89	7.62	0.77
11:23	LT	8	1.00	22.46	3.52	0.60
11:36	LT	9	0.32	0.47	7.07	0.25
10:00	LT	A1	0.20	9.74	12.00	1.28
10:07	LT	A2	0.12	24.47	4.09	0.81
22:00	LT2	1	.	23.67	4.41	0.12

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=61891

TIME	TID	STA	DEP	SAL	DOC	CHLA
5:30	HT	1	.	30.40	1.59	0.03
5:20	HT	2	0.50	30.47	1.85	0.11
5:50	HT	3	0.00	22.89	5.31	0.22
5:50	HT	3	0.50	28.27	2.68	0.67
5:55	HT	4	0.50	30.01	1.87	0.12
6:10	HT	5	0.25	13.92	8.68	1.03
6:25	HT	6	0.25	5.11	13.19	1.01
6:25	HT	6	1.00	0.66	9.83	16.11
6:30	HT	7	0.00	2.52	13.38	0.69
6:40	HT	8	0.25	0.52	14.15	0.51
6:40	HT	8	1.50	17.67	5.07	1.45
6:58	HT	9	0.25	0.06	12.57	0.41
5:40	HT	A1	0.25	14.78	12.74	0.12
5:30	HT	A2	0.00	20.86	6.98	0.15
5:30	HT	A2	0.50	28.81	2.25	1.19
14:52	LT	1	.	17.89	8.73	0.09
14:05	LT	2	0.00	13.47	10.10	0.25
14:05	LT	2	0.50	17.71	8.77	0.27
14:40	LT	3	0.00	16.47	8.50	0.25
14:44	LT	4	0.00	9.46	11.01	0.33
14:44	LT	4	0.50	19.04	6.69	0.36
14:57	LT	5	0.00	2.86	13.63	1.26
15:05	LT	6	0.00	0.79	13.59	1.60
15:05	LT	6	0.50	10.23	9.99	1.07
15:15	LT	7	0.25	0.35	13.39	0.40
15:15	LT	7	1.00	21.77	4.56	0.30
15:30	LT	8	0.00	0.21	13.48	0.58
15:30	LT	8	1.00	17.54	5.22	1.49
15:40	LT	9	0.25	0.10	12.18	0.62
14:25	LT	A1	0.25	4.63	25.36	1.59
14:17	LT	A2	0.12	19.20	10.68	0.81

WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=72192

TIME	TID	STA	DEP	SAL	DOC	CHLA
4:55	HT	1	.	25.987	4.20	0.73
4:42	HT	2	0.10	26.372	3.99	2.38
5:01	HT	3	0.10	4.993	20.69	1.92
5:01	HT	3	0.25	5.463	19.95	2.54
4:52	HT	4	0.10	5.495	17.93	0.43
4:52	HT	4	0.50	23.428	5.61	2.96
5:14	HT	5	0.10	0.277	17.33	8.22
5:25	HT	6	0.25	0.053	15.64	1.58
5:35	HT	7	0.25	0.033	15.04	0.93
5:45	HT	8	0.25	0.023	13.75	0.53
6:00	HT	9	0.25	0.022	13.15	1.16
4:25	HT	A1	0.10	0.735	35.79	1.70
4:34	HT	A2	0.10	5.463	21.00	6.35
4:34	HT	A2	0.25	21.590	7.40	17.12
17:23	HT2	1	.	28.373	2.88	0.79
14:00	LT	1	.	7.960	17.16	1.07
14:07	LT	2	0.10	2.894	18.44	1.90
14:23	LT	3	0.10	6.651	17.56	4.07
14:16	LT	4	0.10	2.377	17.13	2.45
14:16	LT	4	0.45	25.208	4.53	12.59
16:48	LT	5	0.10	0.105	15.61	1.27
15:00	LT	6	0.10	0.041	15.88	0.76
15:08	LT	7	0.10	0.038	14.68	0.46
15:18	LT	8	0.10	0.025	12.60	0.99
15:30	LT	9	0.10	0.041	12.11	0.46
13:47	LT	A1	0.10	0.305	34.24	3.06
13:58	LT	A2	0.10	5.052	27.33	3.65

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=91091

TIME	TID	STA	DEP	SAL	DOC	CHLA
14:20	HT	1	.	31.87	1.66	0.30
14:36	HT	2	0.25	31.76	1.66	0.28
14:09	HT	3	0.25	31.65	1.66	0.52
14:07	HT	4	0.25	31.64	1.51	0.45
13:56	HT	5	0.25	29.44	3.50	4.13
13:44	HT	6	0.25	25.18	5.46	8.75
13:37	HT	7	0.75	20.56	6.46	4.03
13:30	HT	8	0.25	16.68	7.12	4.56
13:23	HT	9	0.10	5.37	9.06	7.12
14:23	HT	A1	0.25	29.72	4.04	3.65
14:17	HT	A2	0.25	30.68	3.05	1.01
10:30	LT	1	.	30.27	3.24	0.29
10:28	LT	2	0.25	29.23	3.49	0.54
10:47	LT	3	0.10	29.83	3.58	2.45
10:39	LT	4	0.50	27.74	3.87	1.28
10:57	LT	5	0.10	21.24	6.02	2.94
11:08	LT	6	0.50	25.84	4.90	2.28
11:20	LT	7	0.10	9.35	8.62	2.07
11:20	LT	7	0.25	21.49	6.37	2.89
11:28	LT	8	0.10	6.45	11.06	2.03
11:28	LT	8	1.25	18.09	7.12	5.19
11:46	LT	9	0.10	0.68	7.98	2.56
11:46	LT	9	0.50	9.86	8.44	15.62
10:14	LT	A1	0.10	20.49	13.08	1.54
10:20	LT	A2	0.10	26.42	7.37	1.26

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=102291

TIME	TID	STA	DEP	SAL	DOC	CHLA
12:00	HT	1	.	26.15	4.93	0.07
11:48	HT	2	0.25	26.63	4.72	0.08
12:13	HT	3	0.25	15.22	13.59	0.14
12:18	HT	4	0.25	20.89	8.12	1.15
12:28	HT	5	0.25	1.95	18.31	0.60
12:37	HT	6	0.25	0.05	14.77	0.18
12:43	HT	7	0.25	0.03	13.82	0.43
12:52	HT	8	0.25	0.02	14.99	0.17
13:05	HT	9	0.25	0.02	13.39	0.43
12:04	HT	A1	0.25	1.88	21.70	1.19
11:56	HT	A2	0.25	4.08	21.90	0.24
8:15	LT	1	.	2.74	19.34	0.28
7:54	LT	2	0.25	1.23	17.03	0.37
7:40	LT	3	0.12	4.45	22.57	1.84
7:33	LT	4	0.25	0.41	14.72	0.46
7:33	LT	4	0.60	22.38	8.25	2.45
7:20	LT	5	0.25	0.05	14.90	11.04
7:06	LT	6	0.25	0.06	13.89	1.52
7:00	LT	7	0.25	0.04	13.96	0.35
6:47	LT	8	0.25	0.03	13.06	0.78
6:36	LT	9	0.25	0.02	14.15	0.74
8:10	LT	A1	0.10	0.61	31.56	0.78
8:03	LT	A2	0.10	2.94	28.20	1.09

BASS HARBOR MARSH
WATER QUALITY DATA FOR THE MARSH ESTUARY

DATE=112890

TIME	TID	STA	DEP	SAL	DOC	CHLA
7:50	HT	1	.	28.00	5.41	.
8:37	HT	2	0.10	29.12	2.70	.
8:37	HT	2	0.50	29.51	2.23	.
17:07	HT	2	0.10	2.73	12.35	.
8:52	HT	3	0.10	1.63	13.05	.
8:52	HT	3	0.25	25.50	3.68	.
8:45	HT	4	0.10	2.41	11.60	.
8:45	HT	4	0.50	28.04	3.03	.
9:07	HT	5	0.10	0.70	10.83	.
9:17	HT	6	0.10	0.05	9.32	.
9:24	HT	7	0.10	0.05	9.20	.
9:33	HT	8	0.10	0.04	11.01	.
9:42	HT	9	0.10	0.04	7.74	.
8:25	HT	A1	0.10	0.57	21.40	.
8:30	HT	A2	0.10	0.31	14.14	.
17:00	LT	1	.	4.59	.	.
5:35	LT	2	0.10	18.77	6.23	.
5:45	LT	3	0.10	1.36	18.51	.
5:55	LT	4	0.25	1.22	12.01	.
5:55	LT	4	0.50	12.51	.	.
6:05	LT	5	0.10	0.06	9.88	.
6:17	LT	6	0.10	0.04	9.23	.
6:25	LT	7	0.50	0.04	9.24	.
6:33	LT	8	0.50	0.04	9.36	.
6:47	LT	9	0.10	0.04	8.42	.
5:15	LT	A1	0.10	0.43	21.75	.
5:22	LT	A2	0.10	0.15	22.15	.

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS IN THE ESTUARY

---------- DATE=42292 ----------

TIME	TID	STA	DEP	SAL	TN	TP
4:17	HT	1	.	26.92	18.07	1.96
16:33	HT	1	.	21.03	15.33	0.51
3:58	HT	2	0.25	28.23	15.83	0.66
4:05	HT	3	0.15	2.57	28.01	1.14
4:05	HT	3	0.50	25.24	17.15	0.76
4:13	HT	4	0.10	2.31	24.99	0.28
4:13	HT	4	0.75	26.63	15.80	0.70
4:28	HT	5	0.10	9.99	27.29	0.23
4:38	HT	6	0.25	0.33	20.05	0.32
4:45	HT	7	0.25	0.14	17.80	0.27
4:55	HT	8	0.25	0.03	17.06	0.28
5:10	HT	9	0.25	0.02	18.52	0.26
3:40	HT	A1	0.25	1.20	24.88	0.35
3:45	HT	A2	0.10	3.65	23.85	0.39
3:45	HT	A2	0.50	26.18	13.28	0.67
14:15	LT	1	.	2.35	25.19	0.37
14:06	LT	2	0.25	1.05	27.50	0.32
14:06	LT	2	0.50	21.41	17.90	0.73
14:21	LT	3	0.15	1.02	28.71	0.50
14:13	LT	4	0.10	0.93	29.20	0.36
14:13	LT	4	0.50	23.02	25.94	2.10
14:32	LT	5	0.15	0.19	15.19	0.33
14:42	LT	6	0.25	0.16	27.78	0.30
14:48	LT	7	0.25	0.10	31.15	0.28
14:56	LT	8	0.25	0.02	30.54	0.26
15:09	LT	9	0.25	0.01	29.30	0.30
13:44	LT	A1	0.15	0.16	28.26	0.43
13:51	LT	A2	0.10	1.72	26.58	0.41

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS IN THE ESTUARY

---------- DATE=51591 ----------

TIME	TID	STA	DEP	SAL	TN	TP
13:30	HT	1	.	29.06	17.58	0.79
13:25	HT	2	0.25	29.22	15.41	0.81
13:53	HT	3	0.25	28.35	16.47	0.57
14:00	HT	4	0.25	28.97	14.69	0.56
14:11	HT	5	0.25	21.00	26.85	0.54
14:20	HT	6	0.25	9.76	28.07	0.38
14:20	HT	6	1.00	23.01	26.53	0.52
14:30	HT	7	0.25	5.38	25.77	0.34
14:30	HT	7	1.00	20.84	.	.
14:42	HT	8	0.25	1.58	25.81	0.26
14:42	HT	8	1.50	22.46	23.73	0.51
14:58	HT	9	0.25	0.28	22.32	0.44
13:40	HT	A1	0.25	26.23	21.52	0.71
13:45	HT	A2	0.25	25.63	19.31	0.46
22:00	LT	1	.	23.67	23.25	0.58
10:15	LT	2	0.50	29.46	11.50	0.66
10:36	LT	3	0.20	29.38	19.16	1.10
10:25	LT	4	0.12	17.42	23.44	0.55
10:25	LT	4	0.50	30.01	17.67	1.12
10:45	LT	5	0.12	8.65	23.34	0.57
11:00	LT	6	0.12	2.38	22.01	0.37
11:00	LT	6	0.75	21.26	25.30	0.84
11:10	LT	7	0.40	15.51	25.89	0.67
11:23	LT	8	0.10	0.89	26.09	0.39
11:23	LT	8	1.00	22.46	26.34	0.72
11:36	LT	9	0.32	0.47	27.47	1.06
10:00	LT	A1	0.20	9.74	26.16	0.53
10:07	LT	A2	0.12	24.47	15.50	0.68

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS IN THE ESTUARY

---------- DATE=61891 ----------

TIME	TID	STA	DEP	SAL	TN	TP
5:30	HT	1	.	30.40	9.73	0.58
5:20	HT	2	0.50	30.47	16.46	0.79
5:50	HT	3	0.00	22.89	21.01	0.40
5:50	HT	3	0.50	28.27	17.90	0.94
5:55	HT	4	0.50	30.01	14.52	0.77
6:10	HT	5	0.25	13.92	18.64	0.70
6:25	HT	6	0.25	5.11	33.25	0.56
6:25	HT	6	1.00	10.66	33.52	1.68
6:30	HT	7	0.00	2.52	40.79	0.51
6:40	HT	8	0.25	0.52	47.07	0.52
6:40	HT	8	1.50	17.67	31.18	0.52
6:58	HT	9	0.25	0.06	49.19	0.50
5:40	HT	A1	0.25	14.78	28.13	0.35
5:30	HT	A2	0.00	20.86	21.92	0.46
5:30	HT	A2	0.50	28.81	29.87	1.86
14:52	LT	1	.	17.89	24.86	0.69
14:05	LT	2	0.00	13.47	25.81	0.48
14:05	LT	2	0.50	17.71	23.12	0.69
14:40	LT	3	0.00	16.47	23.54	0.57
14:44	LT	4	0.00	9.46	25.22	0.55
14:44	LT	4	0.50	19.04	26.86	1.05
14:57	LT	5	0.00	2.86	37.49	0.46
15:05	LT	6	0.00	0.79	42.28	0.49
15:05	LT	6	0.50	10.23	38.21	0.68
15:15	LT	7	0.25	0.35	44.26	0.29
15:15	LT	7	1.00	21.77	25.63	0.74
15:30	LT	8	0.00	0.21	43.50	0.69
15:30	LT	8	1.00	17.54	32.93	1.07
15:40	LT	9	0.25	0.10	43.77	0.45
14:25	LT	A1	0.25	4.63	38.24	0.80
14:17	LT	A2	0.12	19.20	27.23	0.80

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS IN THE ESTUARY

DATE=72192

TIME	TID	STA	DEP	SAL	TN	TP
4:42	HT	2	0.10	26.4	17.50	0.79
5:01	HT	3	0.10	5.0	36.77	0.95
5:01	HT	3	0.25	5.5	42.92	1.38
4:52	HT	4	0.10	5.5	33.27	0.60
4:52	HT	4	0.50	23.4	22.75	1.09
5:14	HT	5	0.10	0.3	38.44	0.63
5:25	HT	6	0.25	0.0	34.52	0.34
5:35	HT	7	0.25	0.0	37.91	0.37
5:45	HT	8	0.25	0.0	35.16	0.34
6:00	HT	9	0.25	0.0	31.44	0.34
4:25	HT	A1	0.10	0.7	.	0.99
4:34	HT	A2	0.10	5.5	39.01	1.11
4:34	HT	A2	0.25	21.6	36.48	2.36
14:07	LT	2	0.10	2.9	43.04	0.89
14:22	LT	3	0.10	6.7	46.07	1.16
14:16	LT	4	0.10	2.4	43.71	1.15
14:16	LT	4	0.45	25.2	50.84	3.14
16:48	LT	5	0.10	0.1	39.97	0.73
15:00	LT	6	0.10	0.0	31.40	0.42
15:08	LT	7	0.10	0.0	32.80	0.40
15:18	LT	8	0.10	0.0	31.08	0.39
15:30	LT	9	0.10	0.0	28.60	0.35
13:47	LT	A1	0.10	0.3	83.60	2.27
13:58	LT	A2	0.10	5.1	49.68	1.57

TOTAL NUTRIENT CONCENTRATIONS IN THE ESTUARY

DATE=91091

TIME	TID	STA	DEP	SAL	TN	TP
14:20	HT	1	.	31.87	17.86	1.16
14:36	HT	2	0.25	31.76	13.43	0.74
14:09	HT	3	0.25	31.65	12.53	0.67
14:07	HT	4	0.25	31.64	14.29	0.71
13:56	HT	5	0.25	29.44	23.13	0.77
13:44	HT	6	0.25	25.18	29.84	0.83
13:37	HT	7	0.25	21.49	24.71	0.47
13:37	HT	7	0.75	20.56	20.93	0.48
13:30	HT	8	0.25	16.68	28.03	0.43
13:23	HT	9	0.10	5.37	28.02	0.53
14:23	HT	A1	0.25	29.72	20.76	0.62
14:17	HT	A2	0.25	30.68	16.43	0.64
10:30	LT	1	.	30.27	19.40	0.45
10:28	LT	2	0.25	29.23	21.37	0.43
10:47	LT	3	0.10	29.83	30.58	0.82
10:39	LT	4	0.50	27.74	27.66	0.92
10:57	LT	5	0.10	21.24	29.32	0.75
11:08	LT	6	0.50	25.84	28.65	0.65
11:20	LT	7	0.10	9.35	29.06	0.54
11:28	LT	8	0.10	6.45	33.58	0.64
11:28	LT	8	1.25	18.09	23.33	0.54
11:46	LT	9	0.10	0.68	25.29	0.42
11:46	LT	9	0.50	9.86	26.47	1.06
10:14	LT	A1	0.10	20.49	37.07	0.66
10:20	LT	A2	0.10	26.42	30.11	0.89

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS IN THE ESTUARY

---------- DATE=102291 ----------

TIME	TID	STA	DEP	SAL	TN	TP
12:00	HT	1	.	26.15	17.49	0.98
11:48	HT	2	0.25	26.63	19.02	0.94
12:13	HT	3	0.25	15.22	21.56	0.49
12:18	HT	4	0.25	20.89	21.29	0.88
12:28	HT	5	0.25	1.95	30.97	0.27
12:37	HT	6	0.25	0.06	29.88	0.22
12:43	HT	7	0.25	0.04	27.14	0.16
12:52	HT	8	0.25	0.02	29.00	0.13
13:05	HT	9	0.25	0.02	25.12	0.11
12:04	HT	A1	0.25	1.88	36.60	0.18
11:56	HT	A2	0.25	4.08	29.03	0.29
8:15	LT	1	.	2.74	32.81	0.30
7:25	LT	2	0.25	1.25	30.70	0.29
7:40	LT	3	0.12	4.45	31.89	0.32
7:33	LT	4	0.25	0.41	28.60	0.22
7:33	LT	4	0.60	22.39	34.21	2.07
7:20	LT	5	0.25	0.05	45.94	1.23
7:06	LT	6	0.25	0.05	29.71	0.25
7:00	LT	7	0.25	0.03	28.73	0.13
6:47	LT	8	0.25	0.03	28.53	0.14
6:36	LT	9	0.25	0.02	25.99	0.21
8:10	LT	A1	0.10	0.61	44.48	0.37
8:03	LT	A2	0.10	2.94	31.99	0.28

WATER QUALITY DATA FOR STATION 1 AT THE RTE. 102 BRIDGE

DATE=42292

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
5:17	EB	1	.	25.535	0.81	0.14	15.58	0.89	0.08	.	0.29
6:17	EB	1	.	17.105	3.08	0.00	30.25	1.04	0.00	.	.
7:15	EB	1	.	21.985	2.60	0.06	21.39	0.72	0.05	.	.
8:15	EB	1	.	17.799	1.73	0.01	29.00	0.02	0.00	.	.
9:15	EB	1	.	10.087	3.48	0.00	42.67	0.69	0.00	.	.
10:15	EB	1	.	10.425	2.83	1.24	41.12	0.48	0.00	.	.
11:15	EB	1	.	9.791	3.00	0.00	42.69	0.49	0.00	.	.
12:15	EB	1	.	10.445	1.93	0.55	42.38	0.03	0.01	.	.
13:15	EB	1	.	10.015	2.90	0.00	42.12	0.60	0.00	.	.
14:45	FL	1	.	19.232	3.65	0.53	27.53	0.03	0.00	.	.
15:15	FL	1	.	21.758	1.55	0.13	22.37	0.73	0.10	.	.
15:45	FL	1	.	20.011	1.52	0.00	25.72	0.03	0.00	.	.
16:15	FL	1	.	17.572	2.08	0.01	30.23	0.06	0.00	.	.
4:17	HT	1	.	26.925	1.28	0.96	13.27	0.12	0.19	2.46	0.14
16:33	HT2	1	.	21.030	1.81	0.11	23.54	0.05	0.10	4.48	0.33
14:15	LT	1	.	2.347	4.40	0.00	53.46	2.86	0.00	7.73	0.25

DATE=51591

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
14:20	EB	1	.	29.11	0.00	0.29	4.44	0.69	0.03	2.25	.
14:50	EB	1	.	29.21	0.02	0.33	4.12	0.61	0.06	2.18	.
17:30	EB	1	.	28.72	0.00	0.31	4.80	0.11	0.00	2.42	.
21:00	EB	1	.	25.08	0.00	0.12	8.36	0.13	0.00	3.88	.
10:50	FL	1	.	26.41	0.00	0.07	8.28	1.50	0.00	4.15	.
11:30	FL	1	.	28.98	0.00	0.23	4.53	1.01	0.05	2.47	.
12:30	FL	1	.	30.06	0.00	0.33	3.00	1.23	0.04	2.63	.
13:30	HT	1	.	29.06	0.00	0.19	6.61	1.34	0.00	2.32	0.04
10:15	LT	1	.	27.61	0.00	0.03	6.34	0.97	0.01	4.61	.
22:00	LT2	1	.	23.67	0.00	0.08	10.47	0.21	0.00	4.41	0.12

DATE=61891

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
6:30	EB	1	.	30.19	0.00	0.27	3.83	0.21	0	2.84	.
7:30	EB	1	.	29.73	0.00	0.28	4.75	1.49	0	1.77	.
8:30	EB	1	.	28.57	0.00	0.22	6.43	0.61	0	2.31	.
9:00	EB	1	.	28.76	0.00	0.24	6.06	1.02	0	2.28	.
9:30	EB	1	.	28.78	0.00	0.14	6.11	0.01	0	2.24	.
10:00	EB	1	.	28.30	0.00	0.13	6.54	0.01	0	2.49	.
12:00	EB	1	.	25.40	0.06	0.05	12.27	0.17	0	3.78	.
13:30	EB	1	.	21.48	0.00	0.01	20.09	0.07	0	5.72	.
14:30	EB	1	.	19.30	0.00	0.01	24.11	0.06	0	7.15	.
5:30	HT	1	.	30.40	0.00	0.24	3.80	0.50	0	1.59	0.03
14:52	LT	1	.	17.89	0.00	0.00	26.22	0.07	0	8.73	0.09

BASS HARBOR MARSH
WATER QUALITY DATA FOR STATION 1 AT THE RTE. 102 BRIDGE

DATE=72192

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
5:25	EB	1	.	26.698	0.04	0.25	11.47	0.18	0.05	.	.
5:55	EB	1	.	26.514	0.02	0.27	11.57	0.80	0.05	.	.
6:25	EB	1	.	25.092	0.00	0.27	14.08	0.97	0.00	.	.
7:25	EB	1	.	23.177	0.00	0.16	17.28	1.06	0.00	.	.
8:25	EB	1	.	18.708	0.00	0.21	24.49	0.43	0.00	.	.
9:35	EB	1	.	19.347	0.00	0.23	25.00	1.52	0.00	.	.
10:36	EB	1	.	16.601	0.00	0.22	28.27	0.63	0.00	.	.
11:30	EB	1	.	10.839	0.00	0.05	35.80	0.07	0.00	.	.
13:05	EB	1	.	9.648	0.00	0.00	37.30	0.05	0.00	.	.
14:30	FL	1	.	24.253	0.00	0.22	15.60	3.31	0.00	.	.
15:00	FL	1	.	25.516	0.00	1.44	13.54	0.03	0.00	.	.
16:00	FL	1	.	26.558	0.00	0.54	11.41	0.18	0.04	.	.
16:30	FL	1	.	28.029	0.16	0.52	8.68	2.00	0.05	.	.
17:00	FL	1	.	29.450	0.00	0.16	6.01	0.12	0.00	.	.
4:55	HT	1	.	25.987	0.05	0.22	12.77	0.30	0.05	4.20	0.73
17:23	HT2	1	.	28.373	0.00	0.23	7.96	0.52	0.00	2.88	0.79
14:00	LT	1	.	7.960	0.00	0.00	39.97	1.93	0.00	17.16	1.07

DATE=91091

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
10:00	EB	1	.	31.10	0.00	0.19	6.07	0.08	0.04	3.06	.
11:00	FL	1	.	31.29	1.17	0.18	6.47	0.13	0.02	2.45	.
11:30	FL	1	.	31.38	1.30	2.76	7.49	0.12	0.13	2.17	.
12:30	FL	1	.	31.70	1.64	0.42	6.83	0.03	0.01	1.81	.
14:20	HT	1	.	31.87	0.00	0.32	6.85	0.05	0.00	1.66	0.30
10:30	LT	1	.	30.27	0.00	0.05	5.38	0.06	0.04	3.24	0.29

DATE=102291

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
8:45	FL	1	.	12.10	1.29	0.00	60.01	0.46	0.00	13.78	.
9:15	FL	1	.	18.85	1.78	0.00	40.98	1.99	0.02	10.22	.
9:45	FL	1	.	18.92	0.00	0.00	40.64	0.12	0.00	9.42	.
10:15	FL	1	.	16.84	0.00	0.06	47.49	0.12	0.00	10.98	.
10:45	FL	1	.	26.29	1.91	0.41	22.59	0.08	0.14	5.00	.
11:15	FL	1	.	24.71	0.00	0.19	26.32	0.08	0.00	5.81	.
11:45	FL	1	.	25.98	0.00	0.56	23.45	0.10	0.00	5.06	.
12:00	HT	1	.	26.15	0.00	0.30	22.61	0.09	0.00	4.93	0.07
8:15	LT	1	.	2.74	0.88	0.00	83.19	0.25	0.00	19.34	0.28

BASS HARBOR MARSH
WATER QUALITY DATA FOR STATION 1 AT THE RTE. 102 BRIDGE

DATE=112890

TIME	TID	STA	DEP	SAL	NO2_NO3	PO4	SIO2	NH4	NO2	DOC	CHLA
9:00	EB	1	.	29.60	6.97	0.39	22.02	0.00	0.25	.	.
10:25	EB	1	.	27.63	7.65	0.63	26.82	0.04	0.35	.	.
11:20	EB	1	.	27.94	7.64	0.63	26.17	0.20	0.32	.	.
12:30	EB	1	.	27.15	7.76	0.43	23.75	0.30	0.31	.	.
13:30	EB	1	.	24.43	7.07	0.29	31.33	0.15	0.27	.	.
14:30	EB	1	.	9.49	5.85	0.01	71.45	2.36	0.00	.	.
15:30	EB	1	.	7.16	5.83	0.01	80.62	0.11	0.00	.	.
16:30	EB	1	.	4.61	5.74	0.01	87.57	1.26	0.00	.	.
5:35	FL	1	.	21.22	7.99	0.39	42.56	0.10	0.11	.	.
6:30	FL	1	.	28.13	1.77	0.11	23.08	0.00	0.07	.	.
7:30	FL	1	.	26.58	8.11	0.62	27.01	0.00	0.16	.	.
7:50	HT	1	.	28.00	7.67	0.69	26.52	0.56	0.25	5.41	.
17:00	LT	1	.	4.59	5.71	0.00	87.22	0.84	0.00	.	.

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS AT THE RTE. 102 BRIDGE

DATE=42292

TIME	TID	STA	DEP	SAL	TN	TP
5:17	EB	1	.	25.53	13.91	0.84
6:17	EB	1	.	17.10	20.24	0.55
7:15	EB	1	.	21.98	11.90	.
8:15	EB	1	.	17.80	10.17	.
9:15	EB	1	.	10.09	15.02	.
10:15	EB	1	.	10.42	14.99	0.69
11:15	EB	1	.	9.79	13.87	.
12:15	EB	1	.	10.44	20.78	0.56
13:15	EB	1	.	10.01	19.33	0.50
14:45	FL	1	.	19.23	18.92	1.08
15:15	FL	1	.	21.76	16.72	0.62
15:45	FL	1	.	20.01	10.65	.
16:15	FL	1	.	17.57	16.62	0.60
4:17	HT	1	.	26.92	18.07	1.96
16:33	HT	1	.	21.03	15.33	0.51
14:15	LT	1	.	2.35	25.19	0.37

DATE=51591

TIME	TID	STA	DEP	SAL	TN	TP
10:15	EB	1	.	27.61	15.16	0.59
14:50	EB	1	.	29.21	17.14	0.80
17:30	EB	1	.	28.72	15.91	0.65
21:00	EB	1	.	25.08	21.70	0.59
10:50	FL	1	.	26.41	21.58	1.26
11:30	FL	1	.	28.98	18.70	0.90
13:30	HT	1	.	29.06	17.58	0.79
22:00	LT	1	.	23.67	23.25	0.58

DATE=61891

TIME	TID	STA	DEP	SAL	TN	TP
6:30	EB	1	.	30.19	9.95	0.41
7:30	EB	1	.	29.73	11.36	0.55
8:30	EB	1	.	28.57	13.05	0.57
9:00	EB	1	.	28.76	12.11	0.62
9:30	EB	1	.	28.78	12.79	0.62
10:00	EB	1	.	28.30	13.72	0.50
12:00	EB	1	.	25.40	15.63	0.42
13:30	EB	1	.	21.48	19.13	0.33
14:30	EB	1	.	19.30	22.57	0.33
5:30	HT	1	.	30.40	9.73	0.58
14:52	LT	1	.	17.89	24.86	0.69

BASS HARBOR MARSH
TOTAL NUTRIENT CONCENTRATIONS AT THE RTE. 102 BRIDGE

DATE=72192

TIME	TID	STA	DEP	SAL	TN	TP
4:55	EB	1	.	26.0	16.78	0.86
5:25	EB	1	.	26.7	18.04	1.16
5:55	EB	1	.	26.5	18.04	1.03
6:25	EB	1	.	25.1	22.61	1.20
7:25	EB	1	.	23.2	21.12	1.06
8:25	EB	1	.	18.7	36.90	1.24
9:35	EB	1	.	18.3	32.27	1.06
10:36	EB	1	.	16.6	35.88	1.14
11:30	EB	1	.	10.8	44.36	1.04
13:05	EB	1	.	9.6	46.62	1.08
14:00	EB	1	.	8.0	47.72	1.03
14:30	EB	1	.	24.3	28.51	1.22
15:00	EB	1	.	25.5	27.61	1.12
16:00	EB	1	.	26.6	24.54	1.05
16:30	EB	1	.	28.0	21.19	1.08
17:00	EB	1	.	29.5	15.19	0.91
17:53	EB	1	.	28.4	16.49	1.07

DATE=91091

TIME	TID	STA	DEP	SAL	TN	TP
10:00	EB	1	.	31.10	18.77	0.62
11:00	FL	1	.	31.29	24.85	1.44
11:30	FL	1	.	31.38	20.56	0.81
14:20	HT	1	.	31.87	17.86	1.16
10:30	LT	1	.	30.27	19.40	0.45

DATE=102291

TIME	TID	STA	DEP	SAL	TN	TP
8:45	FL	1	.	12.10	24.70	0.68
9:15	FL	1	.	18.85	31.17	0.85
9:45	FL	1	.	18.92	20.94	0.77
10:15	FL	1	.	16.84	19.50	0.69
10:45	FL	1	.	26.29	19.60	0.99
11:15	FL	1	.	24.71	17.41	0.96
11:45	FL	1	.	25.98	18.37	1.02
12:00	HT	1	.	26.15	17.49	0.98
8:15	LT	1	.	2.74	32.81	0.30

APPENDIX

LIFE HISTORY OF DOMINANT BENTHIC MACROFAUNA

A brief description of the 12 most abundant species or groups found in Bass Harbor Marsh is given below. When possible, this section includes information on distribution and habitat preferences, feeding type and diet, and reproduction and life cycle.

Turbellarians

Detailed information on turbellarians can be found on p. 202-230 in Barnes (1980) and on p. 114-141 in Pennak (1978). The Phylum Platyhelminthes (flatworms) contains three classes of organisms; two are parasitic and one, the Turbellaria, are free-living forms (Barnes 1980). Turbellarians are probably the most primitive of bilateral animals (Barnes 1980). They are unsegmented, usually dorsoventrally flattened, soft-bodied worms without a coelom or appendages (Gosner 1971) and vary in shape from oval to elongate (Barnes 1980). Their name derives from the fact that they are covered with cilia (Arnold 1901) which is used for locomotion (Barnes 1980). Most species are less than 10 mm in length (Barnes 1980).

DISTRIBUTION & HABITAT PREFERENCES: Turbellarians occupy a diversity of habitats; there are freshwater and terrestrial as well as marine and estuarine species (Gosner 1971). The majority of species are marine (Barnes 1980). Although there are a few pelagic species, most turbellarians are bottom dwellers that live in sand or mud, under stones and shells, or on seaweed (Barnes 1980). Some of the lower forms tolerate a wide range of salinities (Gosner 1971).

FEEDING TYPE & DIET: While some of the smaller turbellarians are herbivorous, most species are carnivores which prey on invertebrates small enough to be captured, as well as scavengers which feed on dead animal tissue (Gosner 1971). Common prey includes protozoa, rotifers, tiny crustaceans (water fleas and copepods), snails and small annelid worms (Barnes 1980).

REPRODUCTION & LIFE CYCLE: Some turbellarians reproduce asexually by fission (Barnes 1980) but most turbellarians are hermaphroditic (Gosner 1971). Self-fertilization is uncommon because male and female reproductive systems are largely separate (Gosner 1971). In most species, development is direct without special larval forms (Gosner 1971).

Oligochaetes

Detailed information on oligochaetes can be found in Cook and Brinkhurst (1973), p. 528-548 in Barnes (1980), and p. 275-290 in Pennak (1978). Oligochaetes (Phylum Annelida) are distinctly segmented but are distinguished from polychaetes in lacking parapodia or head appendages (Gosner 1971). Even though oligochaetes may be very abundant in the sea (up to 1 million per m^2 have been reported), there is little specific information on their ecology and taxonomy (Cook and Brinkhurst 1973). However, it is known that some species of oligochaetes are very important in polluted areas; they can dominate organically rich sediments and are very resistant to anoxia (Cook and Brinkhurst 1973, Pearson and Rosenberg 1978, Lopez 1988).

DISTRIBUTION & HABITAT PREFERENCES: Most oligochaetes live on land or in freshwater. Along with chironomid larvae, they dominate the biomass of most freshwater muds (Lopez 1988). However, there are three families of oligochaetes that live in marine waters along the east coast of North America: (1) Naididae, which are brackish-water worms found among floating weeds or actively swimming; they are typically early colonizers; (2) Tubificidae, with many brackishwater species, are commonly found burrowing in sand or under rocks intertidally, especially in areas with freshwater inputs; some species are highly tolerant of polluted waters; and (3) Enchytraeidae, which are mainly found intertidally, often among decaying seaweeds and seagrasses in the upper intertidal zone (Gosner 1978, Lopez 1988).

FEEDING TYPE & DIET: Most oligochaetes are scavengers, feeding on dead organic matter, especially vegetation (Barnes 1980). Many species feed indiscriminately on bottom deposits while others live interstitially and feed only on very small organic particles or browse material off the surface of larger particles (Cook and Brinkhurst 1973).

REPRODUCTION & LIFE CYCLE: Oligochaetes are hermaphroditic, with well-developed reproductive systems. T here is copulation and reciprocal sperm transfer. Fertilization and direct development occur within a cocoon secreted by the clitellum (Barnes 1980). Juveniles resembling small adults emerge from cocoons after a few weeks or months of development (Cook and Brinkhurst 1973). Asexual reproduction is also very common among some species (Barnes 1980).

Capitella capitata

Capitella capitata is from the family Capitellidae, which are simple-bodied, earthworm-like polychaetes (Fauchald and Jumars 1979). Heteromastus filiformis is also a member of this family. *Capitella* builds tubes at or near the sediment surface yet they are probably motile when deposit feeding (Fauchald

and Jumars 1979). Adult Capitella vary in size from 1 to 100 mm and have been found in densities in excess of 200,000 per m^2(Grassle and Grassle 1974).

A detailed examination of life history features coupled with electrophoretic studies showed that *Capitella capitata* is actually a complex of up to six sibling species which represent distinct temporal adaptations to disturbed environments as a result of both their dispersal capabilities and the relative length of their breeding seasons (Grassle and Grassle 1976). As many as five species have been found at one location (Grassle and Grassle 1976).

Capitella is considered an opportunistic species because of such characteristics as a high reproductive rate, early maturation, large population size, and high mortality (Grassle and Grassle 1974). It can exploit bursts in food resources (Tenore and Chesney 1985) but is also capable of overshooting the carrying capacity of an environment when conditions favor rapid population growth (Chesney and Tenore 1985a). *Capitella* is noted for exploiting disturbed environments and when present, this species is usually numerically dominant; there is evidence to suggest though that it is a poor competitor when communities are more diverse (Grassle and Grassle 1974). In the absence of competitors, *Capitella* densities are highly dependent on food resources (Gremare et al. 1989). Chesney and Tenore (1985b) described *Capitella* as unstable (in terms of constancy of numbers) and unlikely to maintain an equilibrium population for very long.

DISTRIBUTION & HABITAT PREFERENCES: *Capitella* is a cosmopolitan species found in both boreal and tropical sediments (Grassle and Grassle 1974). On the east coast of the United States it ranges from the Arctic south to North Carolina (Gosner 1978). *Capitella* lives in a variety of habitats from intertidal and shallow subtidal waters of estuaries (Gosner 1978) to depths below 200 m (Grassle and Grassle 1974). After an oil spill in West Falmouth, Massachusetts, this species was equally abundant in sandy and muddy bottoms (Grassle and Grassle 1974). *Capitella* is euryhaline and has been collected from waters ranging from 0.3 to 36‰. It can withstand low oxygen and other conditions toxic to other species (Reish 1966 in Hiscock and Hoare 1975, Grassle and Grassle 1974). However, *Capitella*'s ranges of tolerance are not unusually high and short-term selection may be a more important factor for survival (Grassle and Grassle 1974).

Capitella is commonly found in sediments rich in organic matter (see references in Watling 1975, Pearson and Rosenberg 1978) and is considered a primary indicator species of organic pollution (Grassle and Grassle 1974, Pearson and Rosenberg 1978). Capitellids are tolerant of poor conditions on bay mud flats and harbor bottoms; *Capitella* and *Heteromastus* in particular seem to thrive in polluted situations (Gosner 1978). Muus (1967) and Wolff (1973), cited in Watling 1975, note that *Capitella* is also found in high numbers at unpolluted sites. This polychaete is also common in unpredictable environments in shallow waters (Grassle and Grassle 1974).

FEEDING TYPE & DIET: All capitellids are considered non-selective deposit feeders which feed by everting a papillose, sac-like pharynx (Fauchald and Jumars 1979). Experiments have shown that *Capitella* cannot handle and ingest large particles because they do not have the biting or browsing capabilities of deposit-feeding mud snails and corophiid amphipods that enable these two groups to utilize larger particles (Phillips and Tenore 1984).

REPRODUCTION & LIFE CYCLE: The life history of *Capitella* is quite variable and many aspects of it are dependent on food availability. *Capitella* has a very high reproductive potential because of a long breeding season and production of a large number of eggs (Warren 1976). While it has been observed to breed throughout the year (Watling 1975, Warren 1976), Watling (1975) observed the greatest abundances of *Capitella* in May and June of each year in Delaware. A sharp decline in numbers followed, reaching a low in late July (Watling 1975); Grassle and Grassle (1974) have suggested that such a decline correlates with a general depletion of food resources. In the fall, *Capitella* recolonized the area (Watling 1975). This species probably does not live much beyond two years (Warren 1976).

Variability in egg number per brood is highly dependent on the amount of food present but also differs between sibling species (Grassle and Grassle 1976). The authors observed that egg number per brood varied from 30 to 2000. The proportion of brooding females also increases with food availability (Gremare et al. 1988) and adults can produce more than one brood (Grassle and Grassle 1974). Grassle and Grassle (1974) observed that time to maturity was only 30 to 40 days at 20°C (they noted other literature estimates were 30 to 60 days); this time is also dependent on food availability (Grassle and Grassle 1976). This short period enables rapid increases in populations even when limited resources may allow production of only a few eggs (Grassle and Grassle 1974).

Newly settled larvae have been found from April through November (Grassle and Grassle 1974). *Capitella* can disperse to new habitats quickly through planktonic larvae which are produced primarily in the summer but may be present in the water column year-round (Grassle and Grassle 1974). Larval development does not always include a planktonic stage though; in some populations, a proportion of developing larvae do not leave the maternal tubes until after metamorphosis (Warren 1976). By producing benthic larvae, *Capitella* can rapidly exploit local concentrations of organic material (Grassle and Grassle 1974).

Polydora ligni

Polydora ligni is a member of the family Spionidae which is among the largest polychaete families in terms of number of species (Blake 1969). *Streblospio*

benedicti and *Pygospio elegans* also belong to this family and some of the general description for *Polydora* applies to them as well.

Polydora ligni reaches about 25 mm in length (Gosner 1971). *Polydora* and other spionids build mud-covered tubes intertidally and subtidally at shallow depths (Gosner 1978). Spionid polychaetes are distinguished by a pair of long palps used for feeding (Fauchald and Jumars 1979). Although sediment-interface feeders such as *Polydora* and *Streblospio* are highly susceptible to predation (Virnstein 1979), their tubes offer some protection (Dauer et al. 1981). *Polydora ligni* was the only species of six spionid polychaetes studied by Dauer et al. (1981) to build a U-shaped tube, both ends of which were used for feeding.

Spionid polychaetes such as *Polydora* and *Streblospio* are considered to be opportunistic species because of such life history strategies as reproduction at an early age, high fecundity, brooding of their young, multiple generations per year, rapid growth, large population size, and ease of dispersion (Grassle and Grassle 1974, Nichols and Thompson 1985). These characteristics result in nearly continuous dispersal and recolonization of disturbed areas (Grassle and Grassle 1974). *Polydora* may be more opportunistic than *Streblospio* based on its life style (Grassle and Grassle 1974), more ubiquitous distribution in eutrophied areas of the world (Pearson and Rosenberg 1978), and its three-fold greater feeding rate and lesser sensitivity to interspecific palp contacts (Dauer et al 1981).

DISTRIBUTION & HABITAT PREFERENCES: *Polydora* has a widespread geographical distribution (Anger et al. 1986). This species is found on the east and west coasts of North America, in the Gulf of Mexico and in northern Europe (Blake 1969). Spionids such as *Polydora* are common and abundant in shallow water and widely distributed in all sediment types (Fauchald and Jumars 1979, Pearson and Rosenberg 1978, references in Table IV in Dauer et al 1981), although Gosner (1978) states that *Polydora* and related genera prefer mud-clay. *Polydora* can be found epifaunally on blue mussels, oysters, and eelgrass (Orth 1973, Kinner and Maurer 1978). Spionids are common in estuaries and extend into brackish water, *Polydora* is considered euryhaline and has been found in sediments where the salinity of the overlying water is < 5‰ (Gosner 1978).

Polydora is commonly found in sediments rich in organic matter (see references in Watling 1975, Pearson and Rosenberg 1978) and can reach tremendous abundances (e.g. Grassle and Grassle 1974). This spionid is considered an indicator species of organic pollution second only to *Capitella capitata* (Grassle and Grassle 1974, Pearson and Rosenberg 1978).

FEEDING TYPE & DIET: Spionid polychaetes can either feed on deposited material or directly from the water column using a pair of grooved, ciliated palps (Taghon et al. 1980, Dauer et al. 1981). They switch between deposit and suspension feeding depending on current flow, suspended particle concentration and population density (Taghon et al. 1980, Dauer et al. 1981, Levin 1981, Dauer

1983). This flexibility in feeding behavior may be common in environments where conditions change rapidly (Taghon et al. 1980, Miller 1984) and enables surfacedwelling species to respond quickly to varying food conditions (Fenchel et al. 1975, Pearson and Rosenberg 1978, Dauer et al. 1981).

Spionid polychaetes suspension feed by waving their palps through the water column; suspended particles that come into contact with the food groove are sent to the pharynx (Dauer et al. 1981). The chance of contact increases as particle size increases but particle retention is dependent on the adhesive strength of the mucus on the palps; *Polydora* is believed to have a stronger mucus than some other polychaetes and so may be able to retain larger particles (Taghon 1982).

Spionid polychaetes have been observed to ingest sediment particles, planktonic organisms and meiobenthic organisms (Daro and Polk 1973, Fauchald and Jumars 1979, Dauer 1980). Late larvae of spionids can successfully feed on phytoplankton (Breese and Phibbs 1972). *Polydora* preferentially ingested glass beads 105-124 ,um vs. 44-62 ,um in size while deposit feeding; however, at high flow velocities they would be less able to retain these larger particles during suspension feeding (Taghon 1982). *Polydora* can feed on particles up to 600 Rm in diameter (Hempel 1957 in Fauchald and Jumars 1979).

REPRODUCTION & LIFE CYCLE: The sexes are separate (Zajac 1986). Watling (1975) noted that although there was evidence of some reproduction during the winter, the biggest increase in *Polydora* abundance in Delaware occurred each May and June, followed by dramatic declines. In the fall, *Polydora* recolonized the area. In laboratory experiments, *Polydora* showed very little larval growth at 6°C; this is consistent with the season of reproduction which is concentrated in the summer during peak temperatures (e.g. Blake 1969, references in Anger et al. 1986).

Spionids have a high fecundity compared to other opportunistic species such as *Capitella capitata* and *Mediomastus ambiseta* (Grassle and Grassle 1974). *Polydora* produces between 1000-2000 (and up) eggs per female (Blake 1969). While the number of eggs produced by *Polydora* and *Streblospio* are not high compared to some benthic animals such as opportunistic bivalves, the brood protection in spionids allows production of more developed larvae. Two or more broods may be produced by each female in a season (Blake 1969, Daro and Polk 1973, Zajac 1986).

The minimum time from metamorphosis (15-setiger stage) to first hatching of offspring larvae (in 3-setiger stage) is 33 days in *Polydora* (Anger et al. 1986). The life cycle may be completed within six weeks (2 weeks in the plankton and 3 weeks to maturity following settlement (Daro and Polk 1973). *Polydora* larvae may dominate coastal zooplankton communities (see references in Anger et al. 1986). Large numbers of planktonic larvae were present in the plankton of the Woods Hole area from March until September (Simon and Brander 1967 in

Grassle and Grassle 1974) and were an important part of the planktonic community in Maine from May through September (Blake 1969). Larvae settle alongside the tubes of previously settled *Polydora ligni* (Blake 1969). *Polydora* may live for up to several years although the more typical life-span is probably between 1 and 2 years, as it is for *Pygospio* (Anger et al. 1986).

Pygospio elegans

Pygospio elegans is a polychaete in the family Spionidae. Some of the general information described under *Polydora ligni* is relevant to this species. *Pygospio* is a tube-dweller which reaches about 15 mm x 0.7 mm in size (Gosner 1971). It has similarities to other spionid polychaetes, including distribution and feeding, but an aspect of its reproduction is unique (see below).

DISTRIBUTION & HABITAT PREFERENCES: *Pygospio* has a wide geographical distribution with dense local populations often indicating organic pollution (see references in Pearson and Rosenberg 1978, Anger et al. 1986). This species occurs on both sides of the Atlantic, and on the eastern coast of the United States it is found as far south as Virginia (Miner 1950). *Pygospio* is common on rocky coasts, between tides and in shallow water, and in crevices among the rocks (Miner 1950).

FEEDING TYPE & DIET: *Pygospio* can employ a number of different feeding strategies: it can filter by building a mucous net within its tube, it can catch plankton with its palps, or it can feed on surface deposits (Hempel 1957a, 1957b in Fauchald and Jumars 1979).

REPRODUCTION & LIFE CYCLE: *Pygospio* reproduces both asexually and sexually; the role and importance of asexual reproduction in its life history is not known (Hobson and Green 1968). During the spring in Barnstable Harbor, a large part of the population reproduced asexually, while a small proportion underwent sexual reproduction (Hobson and Green 1968). *Pygospio* reproduced asexually by breaking into 2 or 3 fragments, each of which then regenerated a head and a tail. Fragmentation was most pronounced in the spring (Hobson and Green 1968). Females with egg capsules were reported from March to May. A female may release 500 larvae, which have a pelagic life of two weeks (Hobson and Green 1968). Two generations per year are produced by *Pygospio* (Anger et al. 1986).

The minimum time from metamorphosis (15-setiger stage) to first hatching of offspring larvae (in 3-setiger stage) is 81 days in *Pygospio* compared to 33 days in *Polydora* (Anger et al. 1986). However, unlike *Polydora ligni* and *Polydora ciliata*, *Pygospio elegans* can develop successfully to metamorphosis at 6°C, with a slight delay as compared to 12°C. This is consistent with the fact that *Pygospio* can

reproduce during almost the entire year, even in the winter (references in Anger et al. 1986).

Scoloplos sp.

The genus *Scoloplos* belongs to the polychaete family Orbiniidae. There are probably three species that could be found in Bass Harbor Marsh: S. *robustus*, *S. fragilis*, and S. *armiger*. Positive identification of species requires microscopic examination of the differences in parapodia, sometimes under a compound microscope depending on worm size (Gosner 1978). All three species will be briefly described below. For a taxonomic key and more detailed information on life history, see Pettibone (1963).

Orbiniids are small to moderately large in size: up to 375 x 10 mm for S. *robustus*, 150 x 3 mm for *S.fragilis*, and 120 x 2.5 mm for S. *armiger* (Pettibone 1963). Their motility is intermediate between errant and sedentary types of polychaetes (Pettibone 1963). Orbiniids do not construct tubes and are freely moving; swimming is accomplished by a sharp opening and closing of a body coil (Pettibone 1963).

DISTRIBUTION & HABITAT PREFERENCES: The geographical distribution for S. *robustus* and *S.fragilis* extends from the Gulf of St. Lawrence south to North Carolina, and Florida, respectively, and the Gulf of Mexico (Pettibone 1963). *Scoloplos armiger* is widely distributed in the world; along the eastern coast of North America it ranges from Labrador to Massachusetts (Pettibone 1963). Orbiniids are common in muddy areas and range from salt marshes to abyssal depths (Fauchald and Jumars 1979). *Scoloplos robustus* and *S.fragilis* can be found in brackish waters (Gosner 1978). *Scoloplos armiger* prefers sandy substrates (Wolff 1973 in Pearson and Rosenberg 1978) and can tolerate low oxygen (Leppakoski 1969 in Hiscock and Hoare 1975). *Scoloplos armiger* is indicative of organically enriched systems (Pearson and Rosenberg 1978).

FEEDING TYPE & DIET: Orbiniids are described as non-selective deposit feeders (Fauchald and Jumars 1979). They burrow in the substrate, aided by a protrusible proboscis, and feed upon organic debris. Their intestines are often filled with sand and debris of shells, foraminiferans, etc. (Pettibone 1963).

REPRODUCTION & LIFE CYCLE: In the Woods Hole region, breeding in S. *robustus* and *S.fragilis* occurred from early July throughout the summer, and July and early August, respectively (Pettibone 1963). In Maine, females with eggs and males with sperm were found in June and July for S. *robustus* and July for *S.fragilis* (Pettibone 1963). *Scoloplos armiger* has as many as four separate spawnings per year. The presence of eggs in cocoons in S. *armiger* may help retain populations in appropriate habitats (Fauchald and Jumars 1979). In orbiniids, yolky eggs may be spawned free or fertilized eggs laid in irregular

ribbon-shaped clusters, gelatinous masses attached to the sand where adults live (Pettibone 1963). Orbiniids may have a very short pelagic swimming stage (3 days in S. *robustus)* or this stage is lacking (S. *armiger)* (Pettibone 1963). Larvae start feeding after metamorphosis (Fauchald and Jumars 1979).

Streblospio benedicti

Streblospio benedicti is part of the polychaete family Spionidae. Much of the life history description under *Polydora ligni* is directly applicable to *Streblospio* and the reader is referred to that section for more information. *Streblospio* lives in tubes and ranges in size from 1 to 20 mm (Watling 1975, Levin 1981). In contrast to *Polydora ligni* which was not observed to move from its tube, *Streblospio* is highly motile, moving as often as every 2 to 3 days to find new food sources or to avoid interspecific palp interactions (Levin 1981, Dauer et al. 1981). *Streblospio* also commonly enters the water column as adults (Levin 1982).

DISTRIBUTION & HABITAT PREFERENCES: Along the eastern United States, *Streblospio* is found from Maine to Florida (Gosner 1978). It is widely distributed in all sediment types and is considered euryhaline (Pearson and Rosenberg 1978, references in Table IV in Dauer et al 1981). According to Gosner (1978), *Streblospio* often shows a preference for sandy mud. *Streblospio* is commonly found in sediments rich in organic matter (see references in Watling 1975, Pearson and Rosenberg 1978) and can reach tremendous abundances (e.g. Grassle and Grassle 1974, McCall 1977, Levin 1982, Levin 1984a). *Streblospio* is considered to be an indicator of organic pollution but not to the extent that *Capitella capitata* and *Polydora ligni* are (Grassle and Grassle 1974, Pearson and Rosenberg 1978).

FEEDING TYPE & DIET: *Streblospio* is a deposit feeder/facultative suspension feeder like *Polydora*. *Streblospio* can process particles > 50 μm in size (Levin 1982) but may be less able to retain these larger particles while suspension feeding (Taghon 1982).

REPRODUCTION & LIFE CYCLE: *Streblospio* is an annual species (Levin 1981) with a life cycle in Delaware similar to that of *Polydora* and *Capitella*: peak reproduction in May and June with a rapid decline in numbers in July, followed by recolonization in the fall and a relatively stable population over the winter (Watling 1975). Grassle and Grassle (1974) agree that *Streblospio* has a life history similar to *Polydora* but report that the period of spawning is shorter for *Streblospio*. Reproduction has been reported from May to October in the Woods Hole region (Grassle and Grassle 1974) while spawning was observed from June to October in the Mystic River estuary in Connecticut (Dean 1965). In San Francisco where the climate is mild, juveniles can be found throughout much of the year (Nichols and Thompson 1985).

Female *Streblospio* brood their young, producing between 144-365 eggs per female (Grassle and Grassle 1974). Two or more broods may be produced by each female in a season (Grassle and Grassle 1974). Levin (1986) showed that nutrient enrichment in mesocosm experiments resulted in enhanced growth and reproduction for *Streblospio,* with increases in body length, segment number, and a doubling of brood sizes. Eggs are incubated in brood pouches for 4-5 days and pelagic life is usually less than 3 days (Grassle and Grassle 1974) but may be as long as 2 weeks (Dean 1965). Maturity is attained approximately one month following settlement of larvae (Grassle and Grassle 1974). *Streblospio* releases its young either as feeding larvae in the water column for a variable period (Dean 1965) or as nonfeeding larvae that settle upon release (Levin 1981, 1984b, Levin and Creed 1986).

Tharyx acutus

Tharyx acutus is a member of the polychaete family Cirratulidae. *Tharyx* spp. reach up to 16 mm in length and have gills extending from just behind the head to midbody or beyond (Gosner 1978). Most cirratulids live buried in the mud or in mud tubes attached beneath rocks (Gosner 1978).

DISTRIBUTION & HABITAT PREFERENCES: *Tharyx acutus* is found in shallow water from Maine to the New York Bight and is abundant throughout Long Island Sound (Gosner 1978). This species thrives in polluted areas and is very common in offshore dumping grounds (Gosner 1978). *Tharyx* spp. are among the most abundant macrofaunal species in the deep sea (Jumars 1975 in Fauchald and Jumars 1979).

FEEDING TYPE & DIET: Cirratulids are selective deposit feeders which feed with cephalic tentacles that move over the sediment surface; a ciliated groove located ventrally on the tentacle carries particles to the mouth (Sanders et al. 1962, Fauchald and Jumars 1979). The genus *Chaetozone* was observed to feed at the sediment-water interface, on both deposited material and suspended particles (Eagle and Hardiman 1977).

REPRODUCTION & LIFE CYCLE: [No information]

Gemma gemma

Gemma gemma is a small (c 5 mm in length) bivalve in the same family (Veneridae) as the quahog *Mercenaria mercenaria.* It lives just below the sediment surface (Nichols 1977) and is very common and often abundant, particularly on tidal flats (Smith 1964). *Gemma* can overshadow all other species with densities from 100,000 m^{-2} to over 400,000 m^{-2}, the majority of which may be recent recruits (Sanders et al. 1962, Sellmer 1967, Green and Hobson 1970, Nichols 1977,

Nichols and Thompson 1985). This clam is a common food for birds (Nichols 1977), crabs and shrimp (Green and Hobson 1970).

Gemma is considered an opportunistic species because of such characteristics as rapid maturity, brooding of young, multiple generations per year, and ease of local dispersion of both juveniles and adults (Nichols and Thompson 1985). These factors make possible near continuous dispersal and recolonization of disturbed areas (Gray 1979).

DISTRIBUTION & HABITAT PREFERENCES: *Gemma* is found from Nova Scotia to Texas and has been introduced to the west coast of the United States (Sanders et al. 1962, Thompson 1982). It is commonly found in shallow subtidal and intertidal marine sand flats (Bradley and Cooke 1959, Sellmer 1967, Green and Hobson 1970, Weinberg 1978, 1983 in Weinberg 1984, Thompson 1982); *Gemma* is rare in muddy sediments (Bradley and Cooke 1959, Sanders et al. 1962). This small bivalve is constantly moved by wave and tidal action (Nichols 1977, Thompson 1982) and its distribution may be more due to chance than substrate selection (Nichols 1977).

Weinberg (1984) cited studies where *Gemma* did not co-exist in high densities with spionid polychaetes (e.g. Bradley and Cooke 1959, Watling 1975, Zajac and Whitlatch 1982) and his experiments showed that *Polydora ligni* preyed on juvenile *Gemma* and interfered with feeding by adult clams. However, Nichols and Thompson (1985) found that *Gemma* and *Streblospio benedicti* distributions were highly correlated and Gallagher et al. (1983) have shown that tube-dwelling species more often facilitate than inhibit recruitment of other species.

FEEDING TYPE & DIET: *Gemma* filter-feeds at the sediment-water interface (Weinberg 1984). Where it is extremely abundant, *Gemma* can very nearly or completely exploit its food resources, which may explain in part why other suspension feeders such as *Mya arenaria* are not commonly found in areas where *Gemma* is abundant (Sanders et al. 1962).

REPRODUCTION & LIFE CYCLE: *Gemma* is dioecious (separate sexes) and ovoviviparous (Green and Hobson 1970) and has direct development (Nichols and Thompson 1985). Its entire life cycle is benthic (Weinberg 1984). The breeding season of *Gemma* extended over a large part of the year in the lower Chesapeake Bay (Fredette et al. 1990). In San Francisco, *Gemma* showed strong recruitment any time between spring and autumn (Nichols and Thompson 1985). In Barnstable Harbor, there were two pulses of recruitment, June and August, the first of which was probably from the release of overwintering broods (Green and Hobson 1970). In New Jersey, some brooding females overwintered with young conceived late in the summer and released them the next summer to avoid harsh fall temperatures; most, however, matured during the spring and released their young during the summer, with a peak release in July (Sellmer 1967). During the winter months there is negligible growth and reproduction and *Gemma* escapes

harsh temperatures by descending to 4 cm or more in the sediment (Green and Hobson 1970).

Gemma broods its young which reduces early mortality (Nichols 1977). Females brood up to 200 embryos (Weinberg 1984) and the number of eggs (10-100) is positively correlated with adult size (2-4 mm; Green and Hobson 1970). The young are released in tremendous numbers at a relatively large size (375-500 µm; Weinberg 1984). They are scattered by wave action which allows them to settle and thrive in areas not already inhabited by members of the same species or other abundant coexisting species (Nichols 1977).

Growth of *Gemma* in northeast estuaries of the United States is strongly seasonal; most growth occurred in the summer in Massachusetts and New Jersey (Green and Hobson 1970, Sellmer 1967) and temperature and food supply were considered important variables (Green and Hobson 1970). Growth production for *Gemma* has been estimated at 2 g m^{-2} yr^{-1} (Nichols 1977) although the author felt that this value was probably low because the 0.5 mm sieve used would miss many small animals. Even still, *Gemma* is much more productive here than the most productive species in other areas where it does not occur (Nichols 1977). *Gemma* reaches the maximum size of ~4 mm in 2 to 3 years (Weinberg 1984).

For a complete comparison of *Gemma gemma* growth and reproduction in Barnstable Harbor, Massachusetts (Hobson and Green 1970), Union Beach, New Jersey (Sellmer 1959) and San Francisco Bay, California (Thompson 1982), see Table 4 in Thompson (1982).

Hydrobia minuta

Hydrobia minuta is a small (about 4 mm) gastropod in the family Hydrobiidae (Gosner 1971). There is little information specifically on *H. minuta* but a great deal of research has been done on other *Hydrobia* species. It is likely that many of these findings are relevant to the life history of *Hydrobia minuta*.

The genus *Hydrobia* is widespread in shallow waters (Smith 1964) where it is an important food for waterfowl and fish (Anderson 1971). *Hydrobia* spp. can be dominant members of the benthic community; e.g. *H. truncata* can reach densities of 10,000-40,000 m^{-2} (Forbes and Lopez 1986); *H. ulvae*, 60,000 m^{-2} (Thamdrup 1935 in Newell 1965); and *H. ventrosa*, 50,000 m^{-2} (Kofoed 1975).

An interesting behavior exhibited by *Hydrobia* spp. is that of floating on surface waters. Its adaptive significance is in dispute but there are several theories: (1) feeding on the surface film while floating may allow exploitation of a different food source (Newell 1962, 1964); (2) floating may be used for dispersal of offspring, and for dispersal of adults to other, perhaps less used areas of the mud

flat for feeding (Anderson 1971); and (3) floating may be an adaptation to crowding (Levinton 1979). *Hydrobia* will not float in concentrations of seawater <~2.1‰ so floating may help control the upstream distribution of this snail (Newell 1964). *Hydrobia ulnae* commonly climbs shore objects in mid-summer (although not in winter) and this is regarded as a way to attain the floating phase (Anderson 1971).

DISTRIBUTION & HABITAT PREFERENCES: *Hydrobia minuta* is found in salt marsh ponds from Labrador to New Jersey (Miner 1950). *Hydrobia* spp. are among "the most important invertebrates in European estuaries and lagoons" (Kofoed 1975). This genus can be found on a wide variety of substrates (Newell 1965, Lopez and Kofoed 1980). It is common in brackish waters; salt marshes; on *Ulva, Cladophora,* and other plants (Gosner 1971); and in sediments with *Zostera, Ruppia,* and *Chaetomorpha* (Kofoed 1975). Sediment type may affect growth: *H. ulvae* from salt marshes reached larger sizes than those on sand and sandy-mud flats (Chatfield 1972). Members of the genus *Hydrobia* are considered euryhaline. *Hydrobia ulvae,* e.g., can tolerate very low salinities (see references in Newell 1964). Species of *Hydrobia* can be abundant on the edges of highly enriched areas under reduced salinities (see references in Pearson and Rosenberg 1978). *Hydrobia ulvae* is one of the species identified by Pearson and Rosenberg (1978) as indicative of enriched environments.

FEEDING TYPE & DIET: *Hydrobia* spp. are deposit feeders which ingest sedimentary parhcles and assimilate associated microorganisms (e.g. Fenchel et al. 1975, Lopez and Levinton 1978). They employ a variety of methods to obtain food including: (1) ingesting small particles (Lopez and Kofoed 1980); (2) "epipsammic browsing" or browsing upon particle surfaces (accomplished by taking particles into the buccal cavity, scraping off attached microorganisms and spitting out the particle); (Lopez and Kofoed 1980); (3) feeding upon plants like *Enteromorpha* and *Ulva* (see references in Newell 1965); and (4) floating at the water surface and feeding upon the microbial film by means of a mucus raft which acts like a food net (Newell 1962).

Sediments inhabited by *Hydrobia* spp. tend to be very heavily grazed (Forbes and Lopez 1986). Is is not known whether *Hydrobia,* which crawls along the bottom, can seek out food-rich patches of sediments (Forbes and Lopez 1986). Many *Hydrobia* spp. feed mainly on benthic diatoms (Fenchel et al. 1975, Kofoed 1975, Lopez and Levinton 1978, Bianchi and Levinton 1984, Forbes and Lopez 1986) and there can be proportionally more diatoms in their guts than in the sediment in which they feed (Fenchel et al. 1975). Ingestion of diatoms results in the greatest growth in *H. ulvae, H. neglecta,* and *H. ventrosa* while bacteria is a relatively unimportant part of the diet (Jensen and Siegismund 1980). In the absence of diatoms though, *H. totteni* can attain limited growth feeding on bacteria (Bianchi and Levinton 1984) and three species of *Hydrobia* are able to assimilate bacteria (attached or clumped cells) as efficiently as diatoms (Kofoed 1975). Detrital input from the sea lettuce *Ulva rotundata* was shown to

supplement diatom growth which in turn provided more food for *H. totteni* (Levinton 1985).

REPRODUCTION & LIFE CYCLE: In *Hydrobia* spp. the sexes are separate and sperm transfer is by copulation (Clay 1960 in Anderson 1971, Chatfield 1972). Females lay fertilized eggs in capsules (up to 40 eggs per capsule) on the shells of live *Hydrobia*, or on sand grams, dead shells, and green algae (Clay 1960 in Anderson 1971). Veligers hatch in 8 to 10 days (Rothschild 1940 and Stopford 1951 in Anderson 1971). *Hydrobia ventrosa* females lay egg cases of one or a few eggs which subsequently develop into crawl-away larvae (Ankel 1930, 1936 in Levinton 1979). The life span of *H. ulvae* is 1 to 2 years (Anderson 1971, Chatfield 1972, and references within both papers).

Hydrobia truncata reproduced toward the end of May in Massachusetts (Mandracchia and Ruber 1990). *Hydrobia totteni* laid eggs and reproduced in early summer (May-June) in New York (Levinton and Bianchi 1981). The primary spawning season for *H. ulvae* in England was from April to September (Chatfield 1972) though Anderson (1971) recorded some spawning in each month of the year. Chatfield (1972) noted that while observations by Anderson indicated that *H. ulvae* may be fairly opportunistic in breeding, the peak of spawning still occurred in the summer.

Gammarus tigrinus

Gammarus tigrinus is a small species of the abundant and widely distributed amphipod genus *Gammarus* (Bousfield 1969, Holsinger 1972). It is a brackish-water, epifaunal species very similar in appearance to the freshwater species *G.fasciatus* (Werntz 1963) and once thought to be one in the same species (Hynes 1954). Mature males and females of the overwintering population are 7.0-13.5 mm in length while summer generations measure 3.5-6.0 mm at maturity (Bousfield 1969). Size at maturity may vary inversely with temperature (Steele and Steele 1972). Amphipods are important prey of fish (Hynes 1954) and epifaunal amphipods are particularly vulnerable to predation (Van Dolah and Bird 1980).

DISTRIBUTION & HABITAT PREFERENCES: *Gammarus tigrinus* is an American endemic found from southern Labrador and the north shore of the Gulf of St. Lawrence (but not Newfoundland) south to Chesapeake Bay, and sporadically to Florida (Bousfield 1973). This species was introduced into the British North Sea region (where it was first described) and is now spreading rapidly in brackish areas (Bousfield 1973).

Gammarus tigrinus is a common and dominant, essentially benthic, species of the upper estuary, in salinities ranging from 1-25‰ (Bousfield 1973). It is found in debris, *Enteromorpha*, and among hydroids *(Cordylophora)*, on stacked pilings, and

the low intertidal region, but is basically subtidal (Bousfield 1973). Epifaunal amphipods such as *Gammarus* spp. may climb or cling to algae, rocks, eelgrass, detritus, etc. (Bousfield 1973). Although most amphipods in New England shallow waters, exposed to wide seasonal and sometimes daily fluctuations in temperature and salinity, are euryhaline, *G. tigrinus* is described as an obligate oligohaline rarely found in full marine salinities (Bousfield 1973). Osmotic regulation by *G. tigrinus* is described in Werntz (1963).

FEEDING TYPE & DIET: *Gammarus* spp. ingest living and dead plant and animal food (Steele 1967). Although they are not considered specialized feeders, observations in Newfoundland suggest the young benefit from a diet containing filamentous algae which appears from February to August-September, peaking in June. The life cycle is timed so that young are released in the spring and summer when algae are very abundant but not in autumn and winter when algae are depleted (Steele 1967).

REPRODUCTION & LIFE CYCLE: A mature female *Gammarus* spp. has long oostegites fringed with setae which lock together to form a brood pouch where the fertilized eggs are incubated (Steele 1967). Offspring hatch as juveniles with no metamorphosing larval phase (Bousfield 1973). *Gammarus tigrinus* is a multiplebrooded species with ovigerous females from April to October (Bousfield 1973). *Gammarus tigrinus* has a low fecundity (Steele and Steele 1972). Reproductive females average 10.0 mm (minimum 6.1 mm) and the average brood size is 35 with an egg size of 0.458 mm (New Brunswick; Steele and Steele 1972). In general, epifaunal amphipods such as *G. tigrinus* have smaller eggs, larger broods, and shorter developmental times compared to infaunal species of similar size and geographical distribution (Van Dolah and Bird 1980).

The following description is for *G. tigrinus* in New Brunswick (Steele and Steele 1972). Eggs of the first brood begin to enlarge in February but are not fertilized until April; the first young may be released from females in May. Females can produce successive broods: when one brood is developing in the brood pouch, the next batch of eggs is developing in the ovary. Subsequent broods are produced during the spring and summer. Young are released from the brood pouch between May and September and even later. The older generation disappears in late summer and so it is the young-of-the-year which produce the next brood in winter; thus the life cycle is annual with individuals living for one year at the most. Most females probably do not breed in the same year they were hatched. In September, oogonia apparently fail to enlarge and oostegite setae is lost; females that were hatched in the spring probably enter the resting stage until February of the next year. The early onset of the resting stage in August may account for its annual cycle in New Brunswick since young usually do not breed until the following spring. Further south the young could reproduce in the same season because of warmer temperatures and smaller size at maturity (Steele and Steele 1972, Bousfield 1973).

Chironomidae larvae

The following information on Chironomidae larvae is from Pennak (1978) unless otherwise noted. The Chironomidae ("true midges") is an extremely complex family of about 4000 described species with worldwide distribution. Midges are part of the Insecta order Diptera which also includes houseflies, mosquitos, horseflies, and gnats. Although adults are never aquatic, many Dipteran families have aquatic larvae and pupae which are found in every type of freshwater habitat, sometimes in tremendous abundances. Most species in the Chironomidae family have aquatic larvae. The classification of larvae into genera and species is difficult. The two most abundant genera of Chironomidae are *Calopsectra* and *Chironomus*.

Chironomid larvae are elongated, cylindrical and slender ("worm-like"), ranging from 2-30 mm in length. These larvae are an important food for young and adult fishes. Most of the more abundant species have a deep red color produced by dissolved hemaglobins in the blood which is where the name "bloodworm" comes from. The hemaglobin acts as a temporary oxygen store and enables larvae to withstand low oxygen conditions (Cantrell and McLachlan 1977). Chironomid larvae, especially of the genus *Chironomus*, are typically the first colonizers of new benthic habitats (see references in Cantrell and McLachlan 1977, Street and Titmus 1979). Great dispersal abilities and high fecundity of the winged adults are important as are characteristics similar to those of early marine colonizers: relatively small, tubiculous, surface deposit or suspension feeders with the capability for rapid growth (Lopez 1988).

Chironomid pupae are distinguished by the head and thorax forming a large mass at the anterior end. They may stay on the bottom in the old larval tube, where they keep water in circulation by movements of the abdomen, or they may swim actively among aquatic plants or near the surface. Pupae come to the surface just prior to when the imago emerges. Chironomid adults are delicate, nonbiting, and usually < 10 mm long. They commonly occur in swarms, particularly near bodies of water and lights at night.

DISTRIBUTION & HABITAT PREFERENCES: Chironomid larvae occur everywhere in aquatic vegetation and on the bottoms of all types of bodies of freshwater. They often dominate the biomass, production and diversity in lake muds (Lopez 1988). There are also intertidal marine species (Lopez 1988). *Chironomus plumosus* is a species found in polluted habitats (see references in Pearson and Rosenberg 1978).

FEEDING TYPE & DIET: Chironomids include deposit feeders, suspension feeders, browsers, and carnivores (Lopez 1988), although Pennak (1978) reports that they are primarily herbivorous, feeding on algae, higher aquatic plants, and organic debris.

REPRODUCTION & LIFE CYCLE: Chironomids spend most of their lives as benthic larvae; the larval stage of several weeks to over two years is followed by a short, nonfeeding, breeding, and dispersal adult stage (Lopez 1988). Reproduction is sexual (Lopez 1988). Eggs may be deposited singly, in masses, or in strings on the surface, bottom, or aquatic vegetation. The duration of the life cycle varies; some species have only one generation in two years while others have several generations in a single year.

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NPS D-140